UNDERGROUND SYSTEMS FOR ELECTRIC LIGHT AND POWER

UNDERGROUND SYSTEMS

FOR

ELECTRIC LIGHT AND POWER

BY

T. C. RUHLING

Member American Institute of Electrical Engineers; Member National Electric Light Association; Vice-Chairman, N. E. L. A., Underground Systems Committee

FIRST EDITION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK: 370 SEVENTH AVENUE
LONDON: 6 & 8 BOUVERIE ST.; E. C. 4
1927

PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS COMPANY, YORK, PA.

PREFACE

This book had its beginning in a few cost records which the author made in the course of his own work on underground electric conduits. From time to time he added explanatory field notes to these cost data in order that they might be of assistance to associates and friends. A number of the engineers who used this material suggested that it should be made available for others engaged in construction work of this character.

As a result the author prepared a series of articles on "Underground Construction" which were published in Electric Light and Power. Following the publication of these articles he received so many requests for reprints that he felt it advisable to prepare a book on this subject. The present text grew out of this series of articles.

The methods of underground electric transmission and distribution have been improved greatly in the past forty years. Nevertheless, the work is, in some ways, still in its infancy. Furthermore, the author has noted through many years that inexperienced men are often put in charge of this important part of the electric light and power system. It is, then, for young engineers who are engaged in this work and for construction foremen that this present book has been prepared. Much of the material has already been published in technical journals and reports of the N. E. L. A. but it has been difficult for the average man to gain ready access to this material.

It is the author's hope that the young engineer and the construction foreman will find in this present book the kind of information which they need.

The author is indebted to several friends for help and encouragement. He desires particularly to record his thanks to Mr. W. W. Smythe, Jr., Mr. C. H. Shaw of The New York Edison Company, Mr. J. W. Sylvester of The Philadelphia Electric Company, Mr. D. M. Simonds of The Standard Underground Cable Company, Mr. E. H. Scofield, Engineer, Twin City Lines, Mr. A. E. Bettis, Vice-President, Kansas City Power and Light

Company, The General Electric Company, The Westinghouse Night School, The Cleveland Electric Illuminating Company, Associated Engineers Company, The Mica Insulator Company and The Orangeburg Fibre Conduit Company.

T. C. Ruhling.

Kansas City, Mo.
March, 1927.

CONTENTS

CHAPTER XIV

CHAPTER XV

CHAPTER XVI

CHAPTER XVII

UNDERGROUND SYSTEMS FOR ELECTRIC LIGHT AND POWER

CHAPTER I

UNDERGROUND CONDUIT CONSTRUCTION

TRENCHING

Test Holes.—The location of the conduit line in the street is usually determined by existing underground structures. Obstructions are found where least expected. To locate possible obstructions, test holes should be dug at every street intersection, at all points where it is planned to build manholes, and at frequent intervals along the line of the proposed trench. The test holes should be dug at least 18 in. wide and, if conditions necessitate, from curb to curb to locate the best available space in which to construct the line of conduit. In many cases, test holes 6 to 8 ft. long, excavated at a right angle to the curb line, are large enough to determine a satisfactory location for the conduit line. At proposed manhole locations, the test hole should be in the form of a cross, the full width, length, and depth of the manhole.

Locating the Trench.—The conduit line should follow as nearly as possible the route determined by the company engineers, but it should not be installed too close to existing water or gas mains, or to the conduit lines of telephone, telegraph, light, power, and railway companies. The trench should be kept at least 1 ft. away from parallel gas and water mains and other conduit lines. Where conditions permit, the conduit line may be installed under the sidewalk or in the parkway between the sidewalk and the curb, at a considerable saving in construction cost.

Marking the Trench Location.—After the location of the trench is determined, it should be marked plainly for the excavating crew. On paved streets, the marking should be done by means

of a chalk line, about 200 ft. long and well chalked. This line is laid on the pavement in correct position and pulled tight. Men placed along the line about 20 or 25 ft. apart snap the line which leaves a plain white mark as a guide for cutting the pavement. On unpaved streets, the trench location should be marked by steel stakes, connected by a line about 200 ft. long which is drawn tight. The width of the trench to be excavated is then marked along the line by workmen with picks.

Removing Pavement.—In removing brick, stone or wood block, break out one or two blocks only, with a pick or a sledge, to get a start. The paving material may then be taken out whole with pick or bar. In removing asphalt, cut a groove on each side of the trench location with an asphalt cutter similar to a pick, having flat chisel-shaped points; or with an asphalt cutter like that shown in Fig. 1. This cutter has proved very

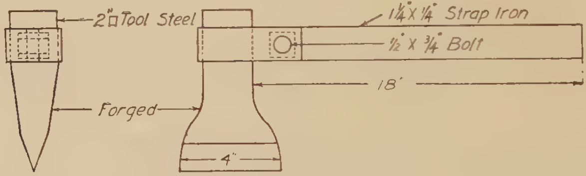


Fig. 1.—Asphalt cutter.

satisfactory. It has an iron safety handle which is held by one man while another strikes the cutter with a sledge. One stroke is sufficient to cut through asphalt. The cutter is moved along the trench line as fast as the sledge man can strike. A clean cut is made so that the asphalt can be taken out in slabs 5 or 6 ft. long. These slabs can be used for a temporary covering after the trench is refilled and until the trench is repaved.

Removing the Concrete Base.—Pick a hole in the concrete base the full width of the trench and about 1 ft. long. Dig out the earth from under the base and with sledges break the base out in large chunks. If the concrete is extra hard it can be cut out with bull-point chisels and sledges. The chisels should be held with safety handles. Use of the paving breaker operated by a compressor is the best method.

Excavating the Trench.—The pavement and base having been removed true to the line locating the trench, the excavating crew will have an accurate guide which will guide in digging the trench straight. The best workmen are likely to dig a crooked

trench or to dig too wide, which will necessitate the use of an excessive amount of concrete. No matter how experienced the excavators are, it is a good plan to furnish them with sticks cut to a length that is 1 in. less than the required width of the trench and have them check their excavations frequently. The trench should be excavated slightly narrower than required for the

FIG. 2.—Leaving section of pavement and concrete base at 12 ft. intervals for the purpose of holding the pavement in place.

completed duct structure; the correct dimension being secured by trimming the sides of the trench. By excavating in this manner, a straight, smooth finish on the sides of the trench is produced which will assist in reducing the quantity of concrete required. The trench should be trimmed to a width that will allow the placing of 3 in. of concrete between the ducts and the sides of the trench. The trench should be excavated to a depth that will allow a covering over the completed duct structure that

measures at all points at least 24 to 30 in. to the finished surface of the street.

In excavating a trench on a paved street, it is a good plan to leave a section of pavement and concrete base about 2 ft. long in every 12 ft. of trench, as is shown in Fig. 2. These undisturbed sections tend to hold the pavement in place and materially brace the ditch at the top. These sections also simplify planking over the trench at night.

The trench should be excavated from one manhole location to the next before grading the trench or laying conduit is attempted, for the reason that even after test holes have been made to locate a clear route, it is possible that obstructions of one kind or another may be encountered which will necessitate changing the grade or the route of the trench.

Mechanical Appliances.—There are many kinds of mechanical implements made by various manufacturers for the purpose of excavating trenches, removing paving and concrete base, and tamping backfill with compressed air.

The portable air compressor which operates paving breakers, jack hammers, clay diggers, and tampers is becoming necessary in the construction of underground electric-conduit systems. By use of this compressor the work can be accomplished with a smaller number of men which will make considerable saving in time and money.

The portable compressor mounted on a standard Ford truck chassis makes an ideal outfit for public service companies. It can be driven quickly from one job to another without delay. Following are some comparisons in time required using pneumatic tools and by hand.

Excavators or trenching machines reduce hand labor considerably and are being used for trenching by many of the public service companies. It is necessary, of course, to anticipate service pipes such as gas and water pipes and these should be located beforehand so that the digging machine will not break them. This is necessary in congested city streets where water and gas service pipes are encountered at intervals of 20 to 35 ft. It is necessary in this case to excavate test holes to locate the various obstructions.

The machines for loading material and surplus dirt on trucks are time and labor savers. The portable elevator or swing crane handling a grab bucket and mounted on a motor truck is a very

valuable piece of equipment. This equipment, however, is high priced for the small job but, when used by various departments in a utility company and kept continually in action, should prove to be very valuable.

The following is a report of the performance of an air compressor and jack hammer:

Operation observed over a period of	5	days
Actual operating time	31	hr.
Idle time	14	hr.
Average operating period per day	6.2	hr.
Average idle time per day	2.8	hr.
Total number of feet drilled	606.5	ft.
Average number of feet drilled per day	121.3	ft.
Average number of feet drilled per hour	19.56	ft.
Total gasoline consumption for period	104.5	gal.
Average daily gasoline consumption	20.9	gal.
Average hourly consumption of gasoline	2.86	gal.
Total consumption of oil (compressor)	3	qt.
Total oil consumption of hammer	1	gal.

Protecting Substructures of Other Companies.—All water and gas mains and telephone, telegraph, light, power, and railway conduit lines should be properly protected while excavating near or around them. Workmen should be cautioned in regard to picking into the conduit lines and starting leaks in gas or water mains. Water and gas mains are very heavy and, if the trench is close to them, they may slide into the trench and cause a large amount of damage. Conduit lines also are very heavy, often carrying cables weighing from 1 to 15 lb. to the duct foot. A large conduit line may weigh as much as 2,000 lb. per trench foot. These facts should be taken into consideration and proper timber supports, wire, cable or chain slings should be used to prevent the pipes and conduit lines from changing their original position while construction is in progress. When backfilling, all tamping under and around these substructures should be very carefully done.

Grading the Trench.—The grade of the trench should be determined by a surveyor's level or by the use of three grading tees. Some men do good work with the tees but a more accurate grade can be secured with the level which is usually operated by the engineer who secures data for the field book. Wooden grade stakes should be driven firmly into the bottom of the trench, 6 ft. apart. The stakes should project 3 in. above the bottom of

the trench to allow the "fine-grade" man to true up the bottom and to serve as a guide for the "bottom concrete" man in placing the 3-in. concrete base. The grade of the trench should not be less than 3 in. per 100 ft. of trench. Grading should be in one direction only and, where this is impossible, should be from a point between manholes toward each manhole. Extreme care should be taken that the grading will not allow pockets to occur in the conduit. Pockets are danger points in a conduit system, particularly in northern cities where water accumulated in the ducts will freeze in winter, crushing the cables and seriously damaging the insulation.

Bracing the Trench.—The necessity of bracing the trench depends upon the nature of the soil excavated. Firm clay will stand up under practically all conditions while clay mixed with sand, stone, or loam is likely to slide from the sides of the trench. Unless braced, the sliding may occur while conduit is being laid, necessitating the removal of earth, conduit, and concrete and then bracing the trench before the laying and concreting of the conduit can continue. The nature of the soil should be studied, and the distance noted between the trench and any gas or water mains or other conduit lines. If the trench parallels any of these substructures less than 3 ft. distant, bracing should be done at once. If the trench is close to street railway tracks, bracing should be done because the heavy traffic is bound to create vibration that will cause the ditch to cave in. A cave-in will not only delay the work but will be dangerous to the workmen as well as the public.

Stringer Bracing of the Trench.—In the majority of places where bracing of the trench is required, 2- by 10-in. or 2- by 12-in. planks placed horizontally, opposite each other in the trench, slightly beneath the base of the pavement, with 4- by 4-in. timbers, or trench jacks between them are sufficient to prevent the sides of the trench from sliding. Trench jacks of the screw type are best for bracing the trench. These jacks can be adjusted easily to almost any required length. When the 4- by 4-in. timber is used for bracing, a heavy sledge is used for driving the braces into place, which sometimes jars the earth loose behind and under the plank stringers thus causing the bracing to lose its effectiveness. When bracing a trench, the braces should be placed high enough to allow for conduit laying underneath. When the trench is over 5 ft. deep it is usually

necessary to use two sets of bracing. If the lower set interferes with the conduit laying, conduit can be laid as high as practicable and concreted; then the lower braces and planks may be removed and conduit laying continued. Figure 3 shows a method of bracing with stringers.

Bracing the Trench in Sandy Soil.—Both sides of the trench should be sheathed or "sheeted" with 2- by 10-in. plank of suitable length dependent upon the ultimate depth of the trench. The planks are beveled on one end for easier driving into the soil; the other end being cut to accommodate an iron driving cap (see Fig. 4). As the excavation of the trench proceeds the planks are driven into the earth, keeping pace with, or slightly in advance of, the excavation. Stringers and braces should be placed as is shown in Fig. 4. If the depth of the trench is over 14 ft., a second set of sheathing must be placed as is shown in Fig. 5. If two sets of sheathing are necessary, the upper part of the trench should be excavated 8 in. wider than the minimum width required

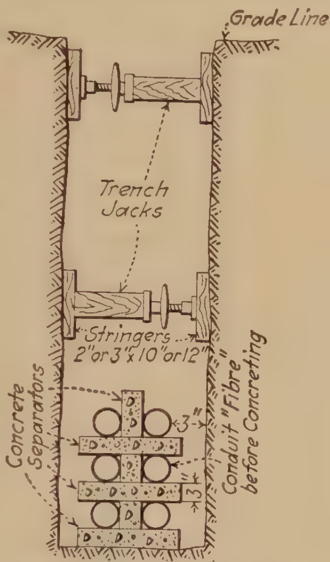


FIG. 3.—Bracing trench with stringers and trench jacks.

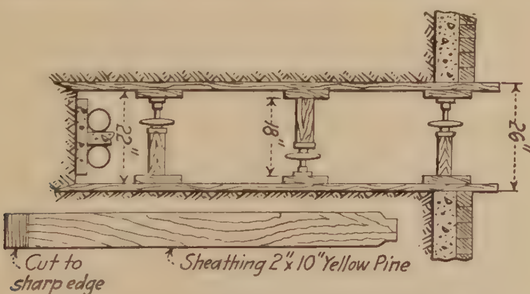


FIG. 4.—Method of sheathing and bracing the trench.

for the conduit structure to take care of the extra width of a second set of sheathing. In sand it will be found necessary to tighten up the trench jacks from time to time as the sides of the trench settle. If the second set of sheathing is driven to a greater depth

than shown in Fig. 5, trench jacks and stringers should remain as shown but an additional set of stringers and trench jacks should be placed near the bottom of trench, leaving room to begin conduit-laying operations. It is also good practice to toenail the upper stringer to keep them from slipping down.

Removal of Bracing from the Trench.—The removal of braces and stringers from the trench is done immediately after the concrete envelope has set sufficiently to permit backfilling

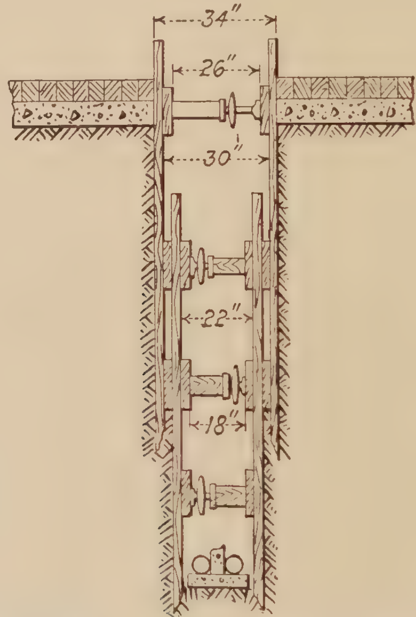


FIG. 5.—Bracing trench with double sheathing for depths over 12 ft.

the trench. The plank sheathing of the trench is not entirely removed until the trench is filled to a point where the sides will be self-supporting. The braces and stringers directly over the conduit-structure are removed first and the trench is backfilled up to the next set of stringers. These stringers with their braces are removed and the backfilling is continued. When the trench is filled to the point where the filling will support the sides of the trench, the sheathing is raised and removed by means of a "clevis and bar." The clevis is made of $1\frac{1}{2}$-in. square mild steel bent into U shape, the inside width of the U being slightly larger than the thickness of the plank sheathing. A handle is

fastened to the U to receive and hold the end of the bar when the sheathing is raised. The bar is made of a wagon tongue or a piece of 4- by 4-in. lumber, about 15 ft. in length. (See Fig.

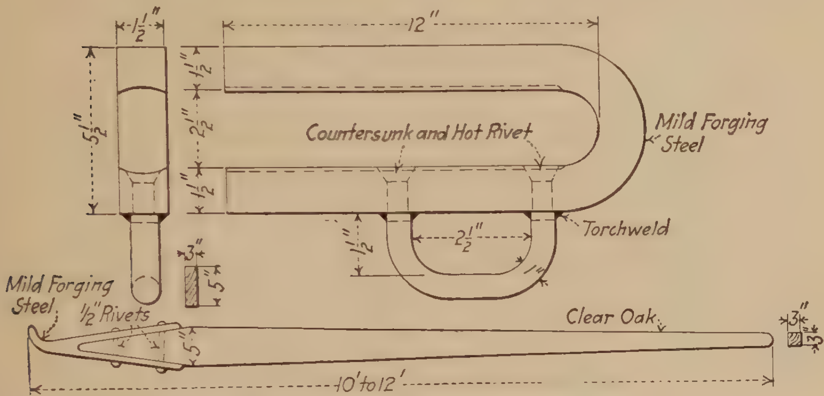


Fig. 6.—Clevis and bar for removing sheathing.

Fig. 7.—The use of a derrick for removing the sheathing.

6 which shows the clevis and bar.) The clevis is slipped onto the plank to be removed as close to the ground level as practicable; the end of the bar is engaged in the collar of the clevis; a fulcrum

is formed with any handy lumber or dirt pile that is near the trench; and the plank is raised by applied leverage. A chain can be attached to the clevis when the sheeting cannot be reached with the wagon-tongue bar.

Another method of raising sheathing from the trench is by means of a log chain wound around the sheathing and fastened to the bar, the planks being removed as with the clevis. The chief objection to the chain method is that the leverage is applied to the corners of the plank rather than to its flat surface as with the clevis, and the chain finally destroys the lumber by slipping and tearing off the corners. The best method of pulling sheeting is to use a small derrick. With this a more direct pull can be made and one man can pull sheeting that would take four men with the clevis (see Fig. 7).

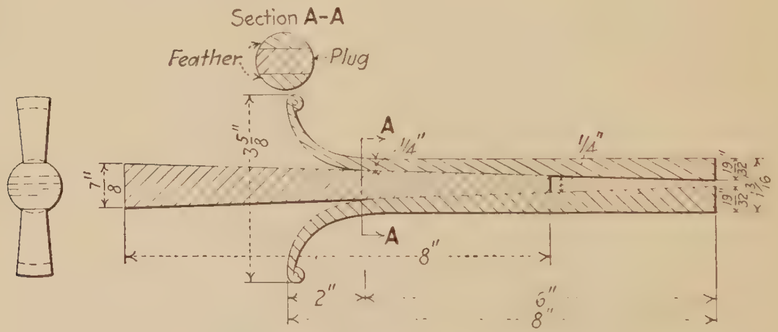


FIG. 8.—Plug and feather for rock excavation.

Excavating Trench in Rock.—The method to be used in excavating a trench in rock depends entirely upon the kind of rock encountered. Some rock is friable and can be picked or worked out with bars. Other rock, in layers ranging from 6 to 10 in., must be drilled, and may be removed with "plug and feather" or wedges. Harder rock, in layers ranging from 12 in. to 12 ft. in depth, must be drilled and blasted out.

Plug-and-feather Method of Excavation in Rock.—Rock in layers ranging from 6 to 10 in. can be excavated by the plug-and-feather method. The plug is a steel wedge; the feathers are two steel wedges inverted (see Fig. 8). The method of excavating with plug and feather is as follows:

A hole, 1 in. in diameter, is drilled into the rock to a depth of about 6 in. The two feathers are then set in the hole and the

plug is inserted between them. The plug is driven down with a sledge. The wedging of the plug between the feathers causes a lifting as well as a splitting effect on the surrounding rock. If there is a seam in the rock, excavation should start at that point. Otherwise, the holes should be drilled down the center line and along the sides of the trench. The holes should be spaced in accordance with the hardness of the rock. This is a good method to use where it is not possible to blast, *i.e.*, under water, gas, or steam mains.

Drilling Rock.—There are several methods used in drilling rock. Where a shallow hole is required, it can be made with a hand drill.

Hand drilling is done by one man who holds and turns the drill with one hand while with the other hand he strikes the drill with a heavy hammer. A laborer using this method can drill from 1 to 3 ft. of hole per 9-hr. day, depending on the hardness of the rock.

Another method is for one man to hold and turn the drill while another man strikes it with a sledge. The two men can drill from 3 to 6 ft. of hole per 9-hr. day, depending on the hardness of the rock.

The best hand method of drilling is with the churn drill which is operated by one man. The churn drill is usually about 7 ft. long, made of 1-in. tool steel with drill points on each end so that when one point becomes dull, the other point may be used. In operating the churn drill, the driller stands upright and lifts the drill, dropping it into the whole with but little pressure on the downstroke. The drill is turned in the hands of the operator with each stroke so as to keep it from sticking. The result of this operation is a round hole in the rock, about 2 in. in diameter and large enough to accommodate easily a stick of dynamite. Using this method, a good operator can drill about 10 ft. of hole per 9-hr. day, depending upon the hardness of the rock.

The best and cheapest method of drilling rock for blasting is through the use of a portable air compressor and jack hammer. One man can drill approximately 20 ft. of hole per hour in hard rock, or as much as 20 men can drill in the same length of time using the churn-drill method.

Drilling and Blasting Shale.—Shale is a soft rock usually found in strata just before reaching solid rock. When first encountered, it may be drilled with an auger drill operated by hand with a T-handle or in connection with a jack-hammer and compressor.

The drill holes in shale should be equal in depth to the width of the trench, and should be located on 3-ft. centers along the center of the trench.

When blasting in shale one to one and one-fourth sticks of 40 per cent dynamite should be used in each hole. If the shale is wet, extreme care should be taken in preparing the charges to be shot. Due to the concussion in the wet shale, the first charge to explode will usually set off any other detonating caps and dynamite that have been placed in the trench.

In dry shale, 10 to 20 charges can be timed by fuse to go off 30 sec. apart so that the shale is shaken loose for easy removal. If so timed in wet shale, the 10 to 20 charges would probably explode at once, tearing up the street and breaking water and gas mains or any other substructures in the immediate vicinity.

Placing Detonating Caps and Exploding the Charges.—The method of placing detonating caps in dynamite is as follows: A piece of soft wood about 6 in. long and 1½ in. square should be whittled down to a sharp, slender point about 3 in. long. This sharp point is used as an awl to make a hole in the side of a stick of dynamite at an angle of about 70 deg. (see Fig. 9).

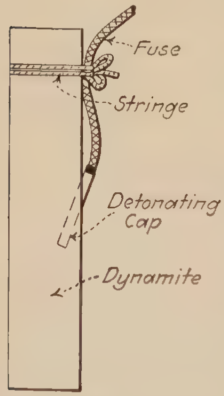


FIG. 9.—Placing detonating cap in dynamite.

In this hole the detonating cap is placed after a fuse is put in the open end of the cap and crimped tightly in place. After placing the cap in the hole the fuse is fastened to the stick of dynamite by tying with twine, which prevents the cap from slipping out when the dynamite is being lowered into the drill hole. (If water is present in the drill hole, it is best to apply lard oil around the end of the cap to prevent water from entering and spoiling the cap.) After lowering the charge into the drill hole, dry dirt or sand is tamped in on top of the charge, filling the drill hole. A good tamper for this purpose is an old broom handle.

Blasting by means of fuses and detonating caps permits loading from one to twenty holes at one time, and exploding them at intervals of a few seconds to 1 min., depending on the length of fuses used. A standard fuse burns at the rate of 1 ft. per minute. When a number of holes are to be exploded at short intervals, the powder man lights the longest fuse first, continuing lighting

fuses down to the shortest which should be of sufficient length to give him plenty of time to get to a safe zone before the first explosion occurs.

Drilling and Blasting Thin Ledge.—Rock in thin layers from 1 to 6 in. thick, running to a depth of 5 to 10 ft., should be drilled 2 or 3 ft. deep. The holes should be located in the center of the trench about 18 in. apart. The charge used should be two to two and one-half sticks of 40 per cent dynamite to each hole. The reason for using so large an amount of dynamite in each hole is that the many thin layers of rock with clay or mud in the crevices tend to dissipate the force of the explosion and cause the loss of a great part of the lifting power of the dynamite.

Drilling and Blasting Hard Rock.—Hard rock is generally found in thick ledges of from 12 to 24 in. The holes should be

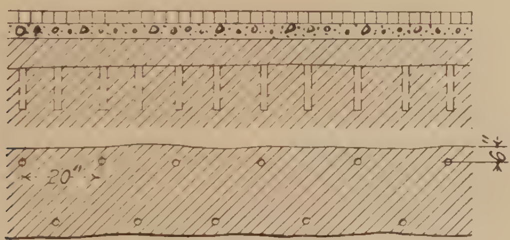


Fig. 10.—Drilling plan for hard rock.

drilled to within 3 in. of the bottom of the ledge, and should be located, zigzag fashion, about 6 in. from the sides of the trench, and about every 30 in. along each side, their position being as shown in the accompanying sketch (see Fig. 10). The drilling plan shown takes into consideration trenches of 24-in. width or less. If the trench should exceed 24 in. in width, it will be necessary to drill a row of holes in the center of the trench.

The charge used should be three-fourths of a stick of 40 per cent dynamite in each hole.

The reason for not drilling through the ledge is to confine the full force of the explosion within the hard rock, breaking it rather than blowing it out of the trench. Less dynamite is required to break hard rock than is needed to break soft rock because the hard rock does not allow the dissipation of the force of the charge.

Each layer of hard rock as encountered is drilled and blasted as explained.

Tunneling through Rock.—In many construction jobs running through rock, it will be found necessary to tunnel under street railway tracks in order to keep the trafficway open. Tunneling in rock can be done in several different ways but the writer's experience has been that the following method is the best for small trenches.

The trench should be excavated to the full required depth up to the point where tunneling is to begin. In the face of the rock to be tunneled, about 12 in. from the bottom of the trench, two or three holes from 12 to 18 in. deep should be drilled downward at an angle of about 20 deg. from the horizontal (see Fig. 11).

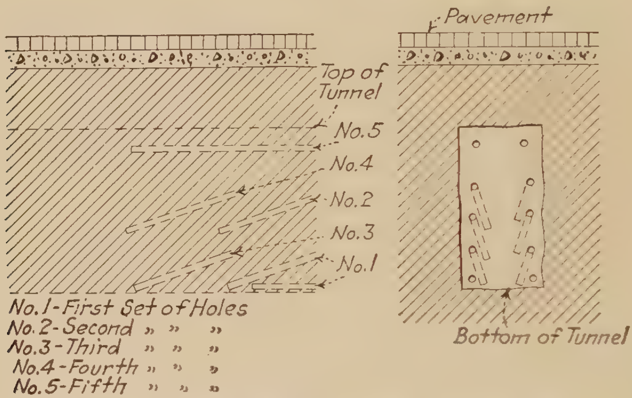


FIG. 11.—Drilling plan for tunnelling through rock.

These holes should each be charged with one to one and one-half sticks of 40 per cent dynamite and exploded. The force of the explosion is downward and out toward the open trench, breaking and loosening the rock at the base of the proposed tunnel. A second set of holes, like the first set, should be drilled into the face of the rock about 12 in. above the opening made by the first "shot."

The second set of holes should be charged with one to one and one-half sticks of 40 per cent dynamite and exploded. All loose rock resulting from the explosions should be cleaned out of the tunnel and trench after each shot. The third set of holes should be drilled in the face of the rock, in the tunnel, at about the same level as the first set of holes, and should be charged and shot.

This process of drilling, charging, and shooting should be continued until a hole has been blasted in the face of the rock at the

bottom of the trench, about 3 ft. long and about 2 to 3 ft. high, and as wide as the ultimate width of the proposed tunnel. Then a set of holes should be drilled in the face of the rock about 12 in. above the large hole just blasted. These holes should be drilled almost horizontally into the rock (see Fig. 11). The depth of this set of holes should slightly exceed the length of the blasted hole directly beneath them. Each of these horizontal holes should be charged with five to seven sticks of 40 per cent dynamite and exploded. The force of the blast will be downward

FIG. 12.—Excavating trench in solid rock.

FIG. 13.—Hand drilling for blasting in rock.

owing to the smaller resistance of the rock directly beneath the charges. If a greater vertical tunnel dimension is required, another set of horizontal holes should be drilled, charged, and exploded. The excavation of the tunnel should proceed in accordance with this method until completed.

Covering Trench for Blasting.—Covering the trench while blasting is very important and should never be neglected. There are several methods of covering. Quite a few construction men use rope mats made up of 2-in. rope woven to a thickness of 6 to 8 in. These mats are placed over the trench, and on the mats heavy timbers or railroad ties are laid to absorb the shock of the blast. The most practical covering the writer has used is made of 3- by 10-in. yellow-pine lumber—four planks, or 3 ft. 4 in. wide—and 8 ft. long. These planks are cleated together on top with three 2- by 10-in. yellow-pine boards. The

under side of the plank is covered with $\frac{3}{16}$-in. mild sheet steel (see Fig. 14). This shock cover is equipped with 3-in. iron rings at the four corners and at each side at the middle, so that it may be carried and placed easily. The shock cover should be laid, lengthwise, over the trench at the point to be blasted, and

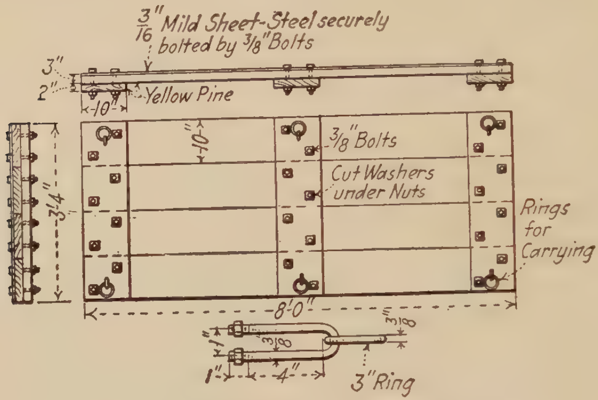


Fig. 14.—Shock cover for blasting.

weighted down with rocks or heavy timbers. Before the charge is exploded, that part of the trench under the shock cover should be shut off from the balance of the trench by bracing planks against the shock cover as shown in Fig. 15. This planking will prevent stones from being blown out of the trench.

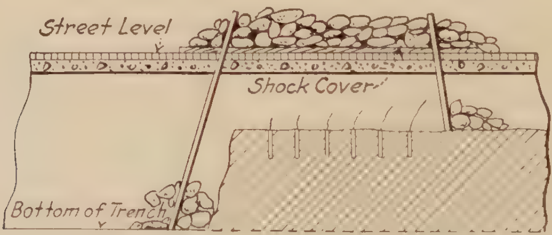


Fig. 15.—Covering the trench for blasting.

Protection of Substructures during Blasting.—If a gas or water main crosses the trench or is otherwise exposed in the trench, it should be protected during the blasting by sacks filled with sand, tied securely in place around the main, so that it will not be damaged by flying rock. If mains or other substructures are within a radius of 6 ft. from the point of blasting, it is unsafe

to use more than one-half stick of dynamite per hole. Great care should be exercised to protect in every way possible adjacent substructures from shock. A broken water or gas main will cause serious delays in construction and will entail great additional expense.

General Note on Drilling and Blasting.—It is impossible for anyone to prescribe exactly how much dynamite should be used for the different kinds of rock; or, how deep the holes should be drilled. No two jobs are just alike. The foregoing paragraphs concerning drilling and blasting must be considered as merely advisory and are based on a very wide experience in rock excavation. It should also be understood that these paragraphs concern the drilling and blasting of narrow trenches wherein the work must of necessity proceed slowly and with great care. As the majority of underground conduit construction is within cities and usually in the immediate vicinity of large buildings and in crowded streets, the local conditions should govern the amount of dynamite used where blasting is necessary. Conditions will arise where it will be unsafe to use explosives and the plug-and-feather method of rock excavation must be used.

Removing Earth from the Trench.—If the trench is not more than 20 in. wide and is 6 or more ft. deep, a windlass with a bucket or canvas bag should be used for removing excavated earth. This method saves labor by obviating the necessity of handling the dirt several times. When the trench is braced, great care should be taken to prevent accident by striking bracing with a heavily loaded bucket or bag which might knock them out and cause a cave-in endangering the lives of excavators. When a deep trench is heavily braced, platforms may be built in the trench so that the bottom men can shovel earth to a man on the platform who in turn will shovel it to the next platform or to the street level as may be required. Where the trench is in rock, the windlass method of earth removal is the better.

Guarding the Trench against Rain.—Heavy rain does great damage to open trench and should be carefully guarded against. If near curb or gutter, the trench should be banked with earth, on both sides, to prevent the rain water from flowing into the excavation from the street. Care should be taken that the ends of the trench are backed and street gutters kept open to the catch basins. If this is not done, heavy rains may come during the night and ruin the trench left open at the close of the previous

day's work. A watchman is practically helpless in the face of a heavy rain as the most he can do is to keep the catch basins open to carry the water from the street. Where precautions have not been taken, the writer has seen the best of bracing drop out during a severe rain; the water, running into the trench, loosens the earth to such an extent that the sides of the trench, from 1 ft. to 5 ft. back, break down and wash into the trench. Accidents of this nature prove to be very costly. Too much care cannot be taken in guarding the trench against rain storms.

Trench Side Forms.—Frequently, during construction, after the trench has been excavated and graded ready for the concrete

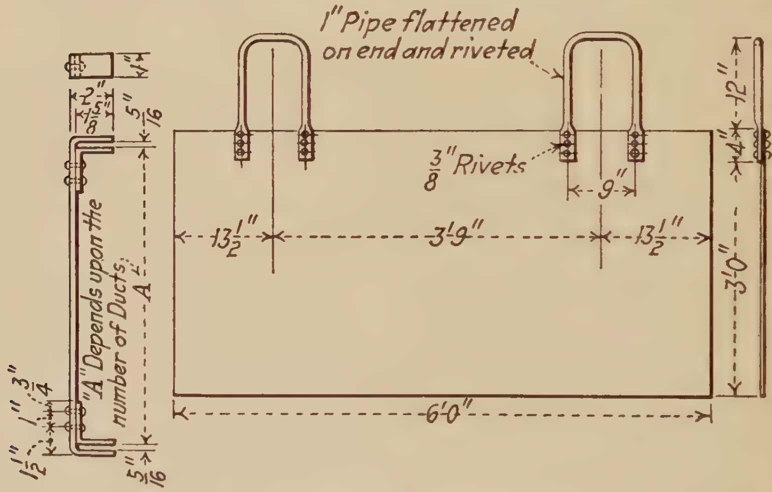


FIG. 16.—Side forms for concreting conduit.

base, a heavy rain comes suddenly and causes the sides of the trench to cave in. To proceed with the construction, it is necessary to clean out the trench, but instead of a trench 18 or 20 in. wide, it may be found to measure 2 or 3 ft. from side to side. To continue the work at the least possible expense, the writer uses steel side forms (see Fig. 16) for holding the conduit structure within correct dimensions during installation. These side-forms can be set up in the trench in a very few minutes, being held in position by the iron cross pieces. Loose dirt is dropped behind the forms, the conduit is laid, and the concrete is poured and tamped. After this the side forms can be removed immediately and set up ahead. Twelve of these side forms are enough to have on the job and will take care of 35 ft. of trench at one time.

It will be found that the side forms, which are made of $\frac{3}{16}$-in. mild steel, can be used for covering over the trench at night; or, they may be used for bridging the trench to allow vehicle traffic to pass. Three pieces of 4- by 4-in. lumber set in the pavement across a 20-in. trench, with the side forms laid thereon, will provide a bridge that can be crossed by ordinary traffic. The sideforms are also found to be useful when pouring the concrete walls of manholes. Two of the forms, laid on top of the manhole forms, are tipped toward the sides of the manhole. Concrete dumped from barrows against the steel side forms will run off into the wall forms. These side forms are also shown in Fig. 17.

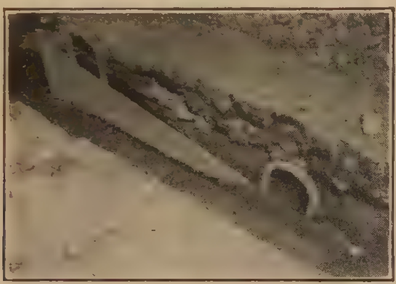


Fig. 17.—Steel side forms for use where cave-in has widened trench.

Protecting the Public.—It is necessary at all times to protect the public from injury to life and property. The trench should be barricaded at all times so that it will be impossible for anyone to fall in trench or manhole excavation. The barricades should be painted red and red lights hung on them at night at all street crossings and street intersections. The trench or manhole should be bridged over at street intersections to allow foot or auto travel.

When paving is being removed, great care should be taken to prevent small stones or pieces of concrete from striking people passing by and to prevent the breaking of windows. Special construction screens of light boards should be built about 3 ft. high at the curb line or near the trench to protect people on the sidewalk and street. These will receive the broken stone or pieces of steel which may come from the tools being used and thus prevent broken windows.

Drills, bull points, and asphalt cutters may become mushroomed from continual striking with sledges. Such tools are very dangerous. Small pieces of steel may break off the head of

one of these tools and strike a window or person. The author has known such pieces of steel to strike and break large plate-glass windows worth several hundred dollars. The board screen will prevent this.

Inspection.—All tools should be inspected by a foreman each day. Picks should be sharp. With a sharp pick more work is accomplished. A dull pick is dangerous because it often slips and glances to one side. This may cause an injury to a man's foot or ankle or to some other man working nearly by.

The best pick to use for stone or concrete is a straight pick, one without the curve that is usually found in the ordinary miner's pick. There is less chance of the straight pick glancing off hard substances like concrete or paving as it strikes the packing with a direct vertical blow.

Goggles should be worn by all men while cutting stone, concrete, or paving. All sledges and pick handles should be sound and if a handle is cracked it should be replaced with a new one at once. If a sledge handle becomes loose it should not be used until fastened securely as the head is likely to come off and injure someone. This is equally true of ax handles, ax heads, etc. When driving sheeting in a trench see that the wood mall is on the handle securely, and that the iron rings which bind the face of the mall are fastened. This precaution should be taken because the man in the trench is liable to be struck by one of these iron rings on his head or hands. The man in the trench must be careful not to place his hand on top of the plank or sheeting being driven by the man driving with the mall. The writer has known a man to reach up out of the trench to pull over sheeting with one hand and the man using the mall working like a machine came down on his hand with the mall, crushing all his fingers. Men become weary and careless and automatic in action and merely go through the motions without seeing or thinking of what they are doing. When driving sheeting, usually an iron cap is used to protect the end of the plank while driving. See that this cap is not dropped into the trench and be careful to place it evenly and solidly over the end of sheeting before it is struck with the mall.

All bracing in the trench should be tested at intervals to see that it is solid. Walking and climbing over braces should be avoided because a man may step on a loose plank and fall to the bottom of the trench causing severe injury.

When using a windlass in deep trenches, inspect ropes, buckets, all fastenings, etc. When the windlass is being used, the men on top should be very careful in lowering the bucket. The man in the trench naturally has his head bent over working in the bottom of the trench and he may be directly under the bucket when it is being lowered. Usually after the bucket goes up the man in the bottom of the trench will be busy making a clear space for the bucket when it is returned.

When moving the concrete mixer by hand for a short distance along the trench or from one side of the street to the other, organization will prevent many accidents. Men are prone to use their hands on wheels instead of putting their hands in some safe place on the machine. The front wheels are very dangerous because a hand may be crushed if the man handling the wagon tongue suddenly pulls it around to make a sharp turn. This may catch the man's hand between the wheel and frame of mixer, or may cause the wheel to run over the man's foot.

Safety Man.—A man who has been hurt on construction work and has spent several weeks in the hospital or at home can be used very advantageously as a safety man around the construction work. This man has had the experience of being injured, due to his own carelessness or the carelessness on the part of another man. He will be keen on the safety idea. It should be his job to walk up and down the trench and watch for danger points, picking up tools left close to the trench which might drop into the trench and injure workmen, and when excavating in rock to see that rock which has been removed from the trench is not likely to roll back. Lumber lying along the trench with nails sticking up, trench jacks lying close to the trench, loose paving at the edge of the trench, unsafe runways for wheelbarrows, wheelbarrows with split handles or broken parts, leaking water hose, improperly piled material, etc., must be watched. This man can make a note of the things he sees during the day and report them to his foreman. Any immediate danger that he cannot correct personally, he should report at once. This man can note water leaks, gas leaks, the condition of pipe or service in trench, and any other items of danger on the construction job. He may develop into a safety engineer if he has common sense, and may save a great many men from injury and cut down liability expense on the construction work.

Be sure the men always know what they are doing and why they are doing it. A good foreman will help his men by passing on to them new ideas and methods which he may have gleaned from reading or which have been passed to him from his superintendent or other foremen. If the common laborer does not hold his pick or shovel in the right manner or to good advantage, it is the foreman's business to show him how. You will win his confidence with a kind word of praise when he shows improvement; let him know you notice it. If you have a lazy man on the job, speak to him about it in a reasonable way and if he is a healthy, honest, and industrious man at heart, he will work, but if he is lazy from habit, get rid of him at once. He will cause you trouble in a great many ways. People passing by your work will notice it and think you are a poor foreman and will not be favorably impressed with the company which employs you and him.

A lazy man is always being hurt or causing accidents to other men. He is usually a trouble maker among his fellow workers and he is the kind of a man who when asked a question by a patron of the company will be insulting in his answer. He will be careless and wasteful in handling material. He may cause a lawsuit by damaging clothing of people passing by and in many ways make trouble for you and your company. It is your business and the business of every man working under you to sell the company to the public by efficient management of the work.

Night Watchman.—This is a very important man at night on construction work. He should inspect every red light to see that it is in perfect order, properly filled with oil, with wick trimmed and globe clean. He should see that the lamp is properly hung and fastened so that if a sudden gust of wind or rain should come it will not cause the lamp to fall or be blown out. He should be on the lookout in windy weather to see that the lamps are burning at all times. One red light out for a few seconds may cause great disaster. He should make his rounds regularly and inspect the condition of trench barricades, tool boxes, material, etc. During and after a heavy rain he should see that no damage is caused by a washout of timbers or bracings and if he cannot replace them himself he should communicate with his foreman, superintendent, or someone responsible who may send help.

Danger Signals.—The red lanterns should be placed so that they can be seen by approaching vehicles and pedestrians at a sufficient distance to give them fair warning from any direction of approach. The lantern should be placed about waist high, not set on the ground nor hidden from approaching traffic by dirt piles or material. An inexpensive and effective form of barricade is shown in Fig. 48.

In case of accidents the night watchman should secure the names of the persons injured and as many witnesses as possible. He should make a complete detailed report in writing to his superiors.

Public Relations.—The foreman or construction man working on the public streets of our cities should consider the rights of others especially as he is employed by a public utility whose main object is to serve the public. It is a recognized fact that whenever a construction crew begins operation in the city streets and tears up paving for excavation, there will be a large number of people who do not understand why this work is being done. If they have property adjoining the construction work they will resent the operation from the standpoint of paying taxes for paving which they feel will not be put back as well as the original paving.

The foreman can make many friends or enemies for himself and the company which employs him. When people ask questions in regard to the construction work at hand, he should be courteous and pleasant under all circumstances. The questions may seem foolish, but they are asked by citizens of the city in which your company is operating and they have as much interest in their city as you have.

Keeping the walks clean in front of private homes or places of business and being courteous at all times will make many friends and the very people who ask you many questions and have many objections will be ready to praise your work and you personally when you least expect it.

When you damage property, be sure you see the owner of the property or his representative and explain in detail how it was done and that you will take care of it at once. A complete and detailed report should be written and sent to your superior. Do not delay, but act at once. The company is judged by your actions.

CHAPTER II

LAYING FIBER CONDUIT

Concrete Base for Conduit.—The concrete base for the conduit should not be placed on loose dirt. If it is necessary to fill in low places in the bottom of the trench, the loose dirt should be tamped carefully. The standard practice of nearly all of the electric utility companies is to construct their conduit systems with 3 in. of concrete enveloping the conduit on top, bottom, and sides. The concrete base for the conduit, therefore, should be at least 3 in. thick and the full width of the conduit plus 3 in. on each side. The base should be of comparatively dry concrete and should be tamped to a smooth surface. The base should be placed in the trench not too far in advance of the conduit laying so that the concrete covering the conduit can establish a firm bond with the base before the base concrete becomes set.

Laying Conduit. The Built-up Method.—Two men in the trench and one man alongside constitute a crew for laying fiber conduit by the built-up method. One man in the trench is the "layer" and the other two men are "helpers." The layer and helper in the trench are each provided with a bundle of twine, cut to correct lengths, tied to their belts convenient to be drawn out for tying the conduit in place. In addition, the helper in the trench has a pot of coupling mixture to paint the conduit joints when they are put together. The helper alongside the trench hands the conduit down to the layer and hands "separators" to the helper in the trench. When a sufficient length of concrete base has been placed in the trench and tamped to an even surface, the laying of the conduit commences. The layer and the helper in the trench lay four pieces of No. 6 hemp twine of proper length and with loops in the ends across the trench on the concrete base. Two lengths being placed at each end of the position to be occupied by the first or bottom tier of conduit. These four pieces of twine are provided for tying the first and second tiers of conduit.

The first tier of conduit is placed on the concrete base with vertical separators between the ducts, one separator at each end. Then the ends of the twine provided for the first tier of ducts are brought around these ducts, pulled tight and tied; the layer tying at one end of the conduit and the helper tying at the other end. Figures 18 and 19 show the method of placing the separators and tying the conduit. After the first tier of conduit is in place and tied, the helper in the trench places the horizontal separators, one at each end of the conduit; and the second tier of conduit is laid thereon. The ends of the pieces of twine provided for the second tier of ducts are then drawn up tight around

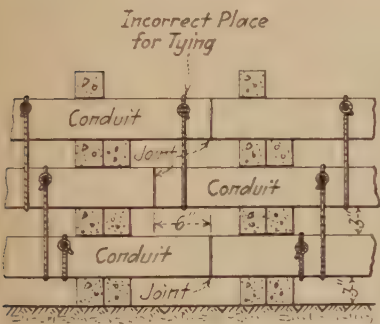


FIG. 18.—Side view of conduits showing the method of placing the separators and tying conduit in the built up method.

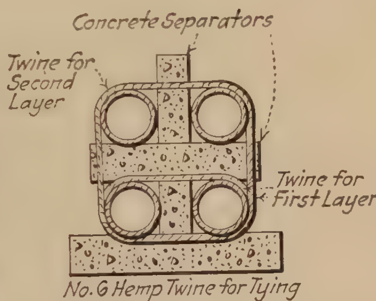


FIG. 19.—End view of conduits showing method of placing the separators and tying twine.

both first and second tiers and securely tied.[1] After the first longitudinal section of conduit is laid as described, the second and succeeding sections are laid, with conduit joints painted, joining the preceding sections, each section being laid and tied in the manner explained.

In laying the conduit, all joints should be staggered, horizontally and vertically, at least 6 in. as shown in Figs. 18 and 19. Staggering of the joints is very important and tends to strengthen the conduit structure as a whole. When joints are laid opposite each other, furthermore, the path of leakage between adjacent cables is materially shortened, and if there should

[1] The method of tying the conduit by tiers is as follows: The first tier is tied alone; the first and second tiers are tied together as are the second and third tiers; the third and fourth tiers; the fourth and fifth tiers and succeeding pairs of tiers until the required multiple of ducts are in place.

happen to be a void in the concrete at this point and one cable failed, it might burn through to the adjacent joint and destroy the cable in that duct. While the writer has never known this to occur in fiber conduit, he believes it is good practice to take this precaution while constructing the conduit system if only for the additional mechanical strength of the structure.

The mechanical strength of the conduit structure installed by the built-up method was shown during the construction of a manhole. A section of the conduit was dug up some months after completion for the purpose of installing a manhole. The conduit structure which was uncovered bridged the manhole

Fig. 20.—Showing method of placing separator and tying conduit.

location for a distance of 12 ft. The conduit structure supported itself with four 400,000-cir.-mil, three-conductor cables installed therein, and seven large men standing in the center of the 12-ft. span. The concrete envelope of the conduit was removed with diamond points and sledges and was found to be free from voids.

Some engineers require that muslin tape be wrapped around the conduit joints and painted with asphaltum paint or some like compound, when the socket-joint type of conduit is used. The experience of the writer in installing considerably in excess of 5,000,000 ft. of fiber conduit since 1908 is that the joints are so accurately made that it is not necessary to use paint or compound to assure a tight fit at the joints between conduit lengths. The compound or the tape and paint, however, are small items

of expense and this additional cost is cheap insurance for an extra rugged joint where inexperienced men are installing the conduit.

The experience of the writer has proved to his satisfaction that fiber conduit installed by the built-up method will save time and material when compared with the tier-by-tier method, besides insuring the best kind of a concrete envelope for the conduit. Installation of conduit by this method makes certain the perfect bonding of the entire concrete envelope. No horizontal joints in the concrete are possible with this method as is often the case when conduit is installed one layer or tier at a time. These horizontal joints are very likely to occur in a system where the concrete covering of each tier of ducts is allowed to secure a firm enough set to permit the layer and helper to walk thereon in laying the next tier of conduit. Where horizontal joints occur in a conduit system, moisture can enter, and freezing expands and separates the conduit structure into layers.

Conduit installed by the built-up method, using a concrete separator will not float or change position during the concreting operation. In the early years of conduit installation by this method the writer used 1-in. square wooden sticks for separators, leaving them in place in the concrete envelope. More than 1,000,000 duct-ft. were laid with this method with good success. Some companies find it necessary to weight down the conduit while concrete is being poured. Cast-iron weights of approximately 100 lb. each are placed on the tied conduit structure, about 5 ft. apart. The writer has used the built-up method of conduit installation for years and has had most satisfactory results with both concrete and wooden separators; but never experienced any trouble with the conduit floating. The writer is now using concrete separators in the bottom of the trench—that is, after the trench is properly leveled, separators are laid in the trench and are graded with level. Two separators, 3 in. square are placed every 5 ft. on the bottom of the trench. The first tier of conduit is laid and tied as previously explained. By installing the conduit in this manner it is possible to pour the entire concrete envelope in one operation.

Mixing and Placing Concrete.—Concrete for conduit work should be made of portland cement; clean, sharp sand, that is free from clay and loam; and broken or crushed stone that is clean and free from foreign substances. For enveloping the conduit structure, the proportions of the concrete should be one part

of portland cement, three parts of sand, and five or six parts of crushed stone. The cement to be used in the concrete should be tested from time to time, to determine its breaking strength.

It is important that the concrete should be proportioned properly. A convenient form of measure for sand and broken stone is a barrel without top or bottom, as it is easily filled and more easily dumped. A wheelbarrow of known capacity is also a handy unit of measure.

Materials for concrete should be placed about every 200 ft. along the line of the proposed trench, at the points where the mixing can be done most advantageously. With this separation of materials, the concrete can be wheeled both ways along the trench, making the longest barrow trip 100 ft. from the mixer. The amounts of cement, sand, and stone placed every 200 ft. will be in accordance with the proportions of the concrete mixture and the estimated cubic yards of concrete required for each 200-ft. section. For example: If an eight-way duct line, 2 ft. wide and 4 ft. high, of 4-in. fiber conduit is to be installed with a concrete envelopment of 3 in. on top, bottom, sides, and between the ducts, the material required for every 200 ft. of trench would be about 90 to 95 sacks of cement, 10 cu. yd. of sand, and 20 cu. yds. of stone, if a 1:3:6 concrete mixture is specified. (See Tables A and B, p. 35.

Protecting Cement on Construction Work.—The usual method for storing concrete along the conduit construction trench is to cover 100 to 200 sacks of cement with canvas or tarpaulin. This cement is usually placed at 100- or 200-ft. intervals on the work and it has been the experience of the writer that, as a whole, a great many sacks of cement are destroyed due to the fact that either the men are careless in covering the sacks with the canvas, or during the night a heavy storm beats the water through the canvas and with a heavy wind lifts the canvas up. This causes a great deal of waste and can be avoided by the use of a small cement shed. Figure 20*a* shows a cement shed designed by the writer for this purpose which will hold 200 sacks of cement. The cement is always kept dry and off the ground so that no moisture enters. This cement shed is portable and is put up in 30 min. It is made in six parts, two long sides, two ends, the floor and the roof which are all hooked or bolted together. As the work progresses, the cement shed can be either moved as a unit or taken apart and moved in sections. This

cement shed has had considerable use in the past and has proved to be very satisfactory.

The sand and stone should be placed close together for efficiency in handling during the mixing operation. Water is secured from city fire plugs by means of a reducer with ¾-in. valve to which a hose is connected and run to the mixer. If the run is a long one, ¾- or 1-in. iron pipe is connected and laid in the gutter to the mixer.

Mixing Concrete by Hand.—Mixing by hand should be done on a flat, water-tight platform. The sand for the batch should be measured and spread evenly on the platform. The measured

FIG. 20*a*.—Portable cement shed.

cement should be spread on top of the sand. Then the sand and cement should be turned with shovels at least three times or until a thorough mixture of these two aggregates is indicated by a uniform color. When the dry sand and cement have been mixed, the correct proportion of broken stone (thoroughly wet) should be spread over the top and the whole turned with shovels at least three times, water being added on the second turning; the quantity of water varying according to the requirements of the concrete. For general use in conduit construction, sufficient water should be used to produce a mushy mixture just too soft to bear the weight of a man when the concrete is in place.

Mixing Concrete by Machine.—Mixing concrete by machine should be done on all large jobs as a measure of economy. A

mixing machine having a capacity of 7 cu. ft. is the best size for conduit work and it should be equipped with a power-charging skip of the pivoted type, with closed end, controlled by a friction clutch. In the charging position, the skip should slant at an angle of 48 deg., which assures a swift slide of the material with sufficient momentum to prevent choking. An automatic clutch releases when the skip reaches the charging position, and simultaneously a brake is automatically applied which holds the skip in position until released. The mixing drum should be of liberal dimensions providing plenty of space to mix a capacity batch without slopping. A water-measuring tank is a good

FIG. 21.—The usual location of concrete mixer.

accessory to have in connection with the mixing machine. With it the water supply for the mixer can be quickly regulated so that the flow is rapid and the quantity delivered is accurate.

Reconstructed Concrete Mixer.—The ordinary concrete mixer on the market today is designed for building construction or paving work. The mixer is usually set up in a convenient location for the work at hand and it becomes necessary to wheel the concrete from the mixer to the place where concrete is to be poured.

It has been the practice in conduit construction to set the mixer up at intervals of every 100 ft. or more as the work progresses. Either the mixer is set on the opposite side of the street or it is placed alongside the trench. Or the mixer can be moved along the trench and concrete poured directly from the mixer into the

trench on streets where there is available room. Using the ordinary mixer with the side skip for this purpose, there is usually not enough room on most streets with the street railways and other traffic together with excavated earth, rock, and other

FIG. 22.—Reconstructed mixer to enable pouring concrete direct into trench.

material. It is necessary to have one side of the trench clear to run the mixer alongside. This clear space must be at least 21 ft. in width, when the width of the trench is taken into considera-

FIG. 22*a*.—Showing steel plate over trench for loading.

tion—which is usually 2 to 5 ft. from the curb—the 12 ft. for the mixer and about 4 ft. outside of the skip when down for loading. Figure 21 shows the usual location of the concrete mixer on the opposite side of the street from the trench. The concrete is

wheeled in a barrow to the trench. If concrete is wheeled a long distance, the aggregate separates leaving water on top, and when it reaches the trench it is necessary to mix it again in the wheelbarrow before pouring into the trench.

Fig. 22b.—Close-up view over trench.

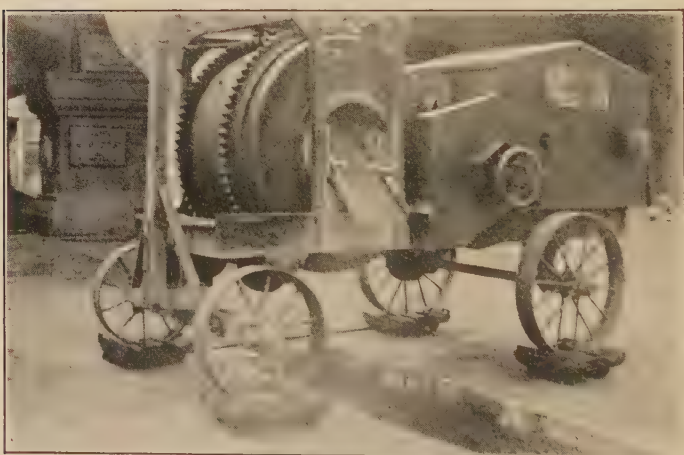


Fig. 23.—Concrete mixer mounted on box trucks for convenience in pouring concrete.

For experiment and test, a mixer as shown in Fig. 23 was mounted on box trucks for convenience in pouring concrete into the trench. After several weeks of test and observation a mixer similar to the one shown in Fig. 22 was reconstructed to comply with the needs of conduit construction work. It can be placed

over the trench to pour concrete directly into the trench, resulting in better and cheaper concrete. This mixer is shown in Figs. 21 and 22. The writer would suggest, however, that this plan be extended to include gears and a chain to drive the rear wheels and a steering wheel connected to the front wheels so that the operator can readily move along the trench without the use of men.

With the reconstructed mixer, the material is distributed along the trench and wheeled into the skip. In order that the men can wheel into the skip, 1/4-in. steel plate is laid down over the trench by the skip. These plates can be made fast to the mixer and moved along with it. This mixer has proved very satisfactory both in saving of labor and material and in producing better concrete.

The Machine Concrete Mixing Crew.—This crew consists of one man who operates the mixer, supervises the proportions of the mixture, and attends to the water supply; one man who shovels sand into the loading skip of the mixer; and one man who shovels rock into the loading skip. The man who shovels sand, having the least shoveling to do, attends to putting the cement into the loading skip. The quickest way of loading a machine is for the men to shovel the sand and rock directly into the loading skip of the mixer from the sand and rock piles. In this case, the men count the number of shovels of each aggregate as they put them into the skip. (The number of shovels of either sand or rock to be placed in the skip for each sack of cement is predetermined by shoveling sand into a wheelbarrow of known 3 cu.-ft. capacity.) Thus, for 1:3:6 mixture, one sack of cement (1 cu. ft.) is dumped into the loading skip when the number of shovels of sand, sufficient to load a 3-cu.-ft. barrow, has been placed in the skip; and two shovels of rock have been placed in the skip for each shovel of sand. After a short time, the proportioning of the aggregates by the mixing crew becomes almost automatically accurate. If the aggregates must be wheeled to the mixer, the proportioning for a 1:3:6 mixture is one sack of cement (1 cu. ft.); one wheelbarrow of sand (3 cu. ft.); and two wheelbarrows of rock (6 cu. ft.); the sand and rock being shoveled from the barrows into the loading skip of the mixer.

The Concrete Placing Crew.—This crew consists of six men wheeling concrete from the mixer, where each man fills his own barrow by pulling down the unloader, to the trench where he

dumps the concrete as directed by a man who stands on the opposite side of the trench and guides the barrow as it is tipped sideways to unload. If any concrete remains in the barrow, this man cleans it out with a shovel. As the concrete is dumped into the trench, another man tamps it into place with a spade tamper. Each barrow man wheels 2 cu. ft. of concrete to a load. The mixer delivers 6 to 7 cu. ft. per batch. Thus, three barrow men are kept delivering concrete to the trench while the other three barrow men are returning from the trench for concrete. When the pavement is rough, planks should be laid for runways.

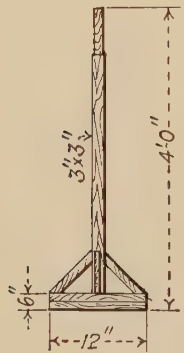


FIG. 24.—Wooden tamper for concrete in bottom of trench.

When mixing concrete with a mixer, the best method is to pour directly from the mixer to the trench. This can be accomplished by moving the mixer over the trench as fast as concrete is placed. A small paving mixer would work out best with a capacity of 7 cu. ft. per batch. Most conduit trenches are not over 36 in. in width. This will permit the wheels of the mixer to span both sides of the trench. Plank runways can be built behind and up to the mixer so that the barrowman can wheel material directly into the charging skip, mixing the aggregates and discharging directly into the steel trough, thence to the conduit in the trench. This will eliminate the trouble of concrete becoming set in the barrows in transit to

FIG. 25.—Spade tamper for tamping concrete between ducts.

the trench. This method produces a good quality of concrete and is more economical.

When constructing conduit in a wide street with sufficient space for surplus dirt, etc., an ordinary concrete mixer may be used by running it alongside of the trench, or the mixer may be mounted on small box trucks (see Fig. 23). This method works out very successfully and gives good results.

The equipment for the concrete crew is as follows:

1 wooden tamper for bottom concrete (see Fig. 24).

1 concrete batch mixer, 7 cu. ft. with 5-hp. gasoline engine; power loader; and water-measuring tank.
8 wheelbarrows.
2 shovels, number 2 scoops for loading mixer.
2 shovels, number 2 straight.
1 spade—tamper (see Fig. 25, p. 34).
2 pails, to be used for washing mixer and tools.
1 concrete chuts (see Figs. 26 and 26*a*, pp. 36 and 37).

TABLE A.—MATERIAL REQUIRED FOR 1 CU. YD. OF CONCRETE

Concrete mixture	Cement, barrels	Sand, cubic yards	¾-in. rock, cubic yards
1:2:4	1.34	0.40	0.80
1:3:5	1.03	0.47	0.78
1:3:6	0.92	0.42	0.84

TABLE B.—HANDY TABLE OF MATERIAL REQUIREMENTS

Concrete mixture	Cement, sacks	Sand, cubic feet	¾-in. rock	Total amount of aggregates used, cubic feet	Approximate total mixed concrete, cubic yards
1:2:4	5.5	11.00	22	38.50	1.02
1:3:5	4.0	12.00	20	36.00	0.95
1:3:6	4.0	12.00	24	40.00	1.06

Pouring Concrete Envelope. The Built-up Method.—Placing the concrete is a very important part of conduit installation and great care should be taken as the best laid conduit structure can be ruined by carelessness on the part of the concreting crew. Small stone should be purchased for use in the concrete. The stone should not be over ¾ in. for enveloping a conduit structure wherein the ducts are separated from each other 1½ in. to 3 in. Where the separation between ducts is 1 in., the best concrete mixture is of cement and torpedo sand. Stone not larger than ½-in. may be used satisfactorily, however, where the ducts are separated 1 in. only. The small stone is necessary to make a concrete grout that will flow freely between the ducts and the grout must be of consistency that will allow a spade tamper (see Fig. 25) to be worked up and down between the ducts and

between the sides of the trench and the ducts, to insure a solid mass of concrete without voids.

The concrete may be poured directly into the trench from the concrete mixer or from the wheelbarrow, or may be shoveled into the trench from the wheelbarrow. Care should be taken in dropping concrete on the ducts as in mass it is very heavy and if dropped directly on the conduit it is very likely to result in a broken duct or a broken joint, or it may push the conduit to one side of the trench throwing it out of alignment. These accidents may be avoided by placing a plank, 5 or 6 ft. in length,

FIG. 26.—Concrete chute.

on top of the conduit structure covering the ducts, and pouring the concrete on the plank from which in runs down the sides and envelopes the conduit from the bottom of the trench.

The best method employed for placing concrete is one developed by the writer which not only saves time but eliminates the possibility of the accidents mentioned in the preceding paragraph. In this method, a sheet-steel trough with a deflecting partition in the center is used (see Figs. 26 and 26*a*). When using this trough, the concrete grout is dumped from the mixer or from barrows directly into the trough which rides the sides of the trench and is immediately over that portion of the conduit

structure that is to be concreted. The deflecting partition of the trough divides the concrete, compelling it to flow to the bottom of the trench between the conduit structure and the sides of the trench, thence toward the middle of the trench where the two deflected portions of the concrete meet and rise filling all spaces between the ducts and between the sides of the trench and ducts from the bottom upward. This method not only reduces the chances of voids or air pockets in the concrete envelope but also gives the concrete another turnover as it goes into place. It may appear that with this method the earth would be washed from the sides of the trench into the concrete. This is not the case. If the sides of the trench are loose enough to be sluffed off by the concrete, they are in considerable danger of

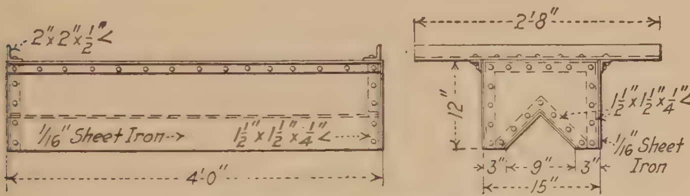


FIG. 26a.—Plan of concrete chute.

breaking away and slipping in, and should be sheathed with lumber or steel side forms, as shown in Figs. 16 and 17, pp. 18 and 19.

Tamping Concrete Envelope. Built-up Method.—If the concrete is poured directly on the top of the duct structure, it is imperative that the concrete be tamped immediately following its pouring, to prevent the forming of voids or air pockets between the ducts. The tamper used for this purpose is made from a hoe, straightened out, and a piece of sheet steel, the same width as the hoe blade, riveted on to extend the blade to a total length of 18 in. The tamper is not to be used as a shovel but should be inserted between the vertical tiers of ducts and between the outside tiers of ducts and the trench wall and worked up and down, the blade reaching the base concrete. This action creates a suction and breaks up any voids that may be forming so that the concrete becomes a homogeneous mass. The spade tamper is shown in Fig. 25.

Backfilling the Trench.—Do not backfill on green concrete. Proper backfilling requires thorough tamping of the dirt as it is replaced in the trench and this tamping should proceed with

care. Tamping the dirt on green concrete is likely to force the conduit out of alignment if laid by the tier-by-tier method; or, however laid, the ducts may be broken or a stone in the backfill may be forced through the wall of a duct, allowing the green concrete to seep in and set. An accident of this nature will not be detected until the ducts are tested with a mandrel. It will then be necessary to excavate and remove the concrete surrounding the duct to repair the damage done.

Two tampers should be employed to each shoveler. Dirt should be shoveled into the trench until a layer of 6 in. covers the concrete envelope and then should be carefully tamped. Good tampers are shown in Fig. 27. Backfilling and tamping should proceed in layers of 6 in. When the temperature is below freezing do not backfill on concrete that is at all green. It is best to cover the concrete with about 6 in. of loose dirt and wait, if necessary, until the next day to backfill. Care should be taken in cold weather not to backfill with large lumps of

Fig. 27.—Dirt tampers.

frozen dirt or ice. The trench is sure to settle as soon as warm weather comes, and even if a good repaving job is done in the spring, the trench will continue to settle and will necessitate paving repair at additional expense. The best tamping is accomplished with an air compresser and sand rammers.

In warm weather the concrete envelope will set rapidly, but backfilling cannot be done properly until the concrete has set about 24 hr.

Laying Fiber Conduit. Tier-by-tier Method.—After the trench is excavated to the desired depth and width and the trench properly graded, the 3-in. concrete base is then placed in the bottom of the trench for about 100 ft. This concrete should not be mixed too wet. Just enough water should be used so that when the concrete is tamped in place, water will not appear on the surface or the concrete should be allowed to set before laying the conduit. If laying is begun on wet or sloppy concrete, it will not support the weight of the men and the result will be an uneven base for the conduit structure.

Two men in the trench and one man alongside constitute a crew for laying fiber conduit by the tier-by-tier method. One man in a trench is the layer, the other two are helpers. The helper alongside the trench has a can of coupling compound to paint the joints of conduit. He hands the conduit down to the layer who faces the duct structure which is being built.

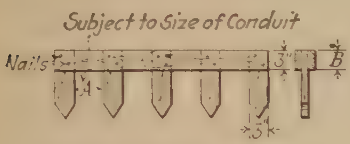


FIG. 28.—Comb separators.

FIG. 29.—Comb separators.

The helper stands over the conduit previously laid and holds the conduit in place. He in turn paints the joints and the layer places the new lengths into this joint with a half-turn to right and left to seat it properly. The helper places near the joint or on each side of the joints the separators as shown in Figs. 28 and 29. These separators are inserted to give uniform separation for

FIG. 30.—Tier by tier method laying fiber conduit.

concrete. The two men move along and lay about 100 ft. and the concrete crew pours concrete to the level of the top of the cone separator after which the cones are removed and openings are filled with concrete.

The crew who wheel the concrete for base are usually the men who pour the concrete for the conduit, that is, as the layer pro-

gresses the concrete crew advances and places another 100 ft. of base or they pour concrete over the conduit.

The men who level the concrete for the base also direct the pouring of the concrete around the ducts. When the first tier

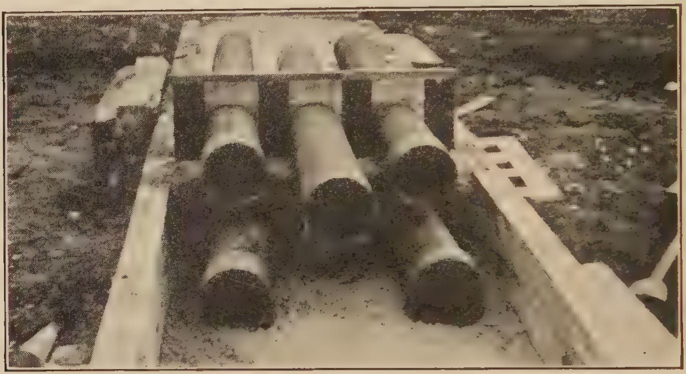


FIG. 31.—Tier by tier method laying fiber conduit.

FIG. 32.—Protection of water and gas service pipes into buildings.

of conduit is covered with concrete, it should be allowed to set before another tier is laid.

The second tier is begun by laying conduit directly on the concrete placed over the first tier. Comb separators for the

second tier and the succeeding tiers should be made without points, and wedged in place on each side of the trench with stones or wooden wedges. If this is not possible a shovel full of concrete placed on each side of the separators will keep them firmly in place (see Figs. 30 and 31).

In laying this conduit all joints should be staggered horizontal and vertical at least 6-in. as previously shown in Fig. 18, for the built-up method (p. 25). Every tier of conduit is laid as directed. The third and succeeding tiers are laid as the second. It is

FIG. 33.—Protection of water and gas service pipes into buildings.

necessary to allow the concrete to set before each succeeding tier is laid in order to get good alignment and proper separation.

Protecting Gas or Water Service to Buildings.—During construction of conduit lines it is not always possible to avoid all obstructions. The writer has found in encountering 1- or 2-in. service pipes that a good practice is to use fiber conduit which has been sawed through lengthwise. The bottom half is laid on top and a piece of tar paper is wrapped around the two sections of fiber duct which are tied in place with twine or wire. This will allow at any time in the future the withdrawal of service pipes for repairs on replacement. This scheme is shown in Figs. 32 and 33.

CHAPTER III

TILE-DUCT CONSTRUCTION FOR UNDERGROUND ELECTRIC CONDUIT

There are various kinds of tile ducts made of clay and vitrified salt glazed. The multiple-tile ducts are made two way, four way, six way, and nine way.

Use of multiple tile is not considered good practice for power cables, though it has been used to a great extent throughout the United States in the past. For a power system having a large number of heavy cables carrying thousands of kva., and where one cable, carrying 6,000 kva. might fail and communicate the trouble to another heavily loaded cable in the adjacent duct through the joint in the multiple-tile duct thus cause a serious interruption, multiple-tile duct should not be used.

Single Duct.—The single duct is much more flexible for construction in congested districts where obstructions make it necessary to divide or split the duct structure to enable the passing of the duct line. The single-tile duct, furthermore, can be so installed that short-circuit trouble can to a great extent be avoided.

It may be said that multiple tile allows cheap construction and occupies less space in the street. Considering, however, the problem of constructing a duct line to take care of heavily loaded, high-voltage feeders, one must consider the permanence of the service given by the duct line. It is more important to build for the future rather than to lay too much emphasis on first cost.

It is apparent that failures in cables of this kind involve a large expense in repairing cables and ducts. The danger to connected apparatus is also a factor to be considered. If tile duct, therefore, is used for power work it should be single-tile duct. The construction should be of a high grade with liberal separation between ducts of 1:3:5 mixture of concrete.

In the past, single-tile duct was laid with approximately $\frac{1}{8}$ in. to $\frac{1}{4}$ in. of lime or cement mortar (see Figs. 42 and 43). This

kind of construction would not stand up under heavy services. A great deal of the trouble was contributed to improper baking and glazing.

Specifications sometimes read as follows: Not more than 2 per cent absorption in 24 hr. in the whole piece and 3 per cent in fragments having about 50 per cent of the surface glazed. Another specification requires not over 5 per cent absorption without defining the conditions as to whole or broken pieces. On the other hand, a great many cases of failure have come to my notice that have proved to be caused by very poor construction methods and material.

To construct conduit lines with single-tile duct for electric power transmission, the tile should pass rigid inspection for glaze, vitrification, and absorption, and the glaze should thoroughly cover the inside of duct so that there will be a smooth surface for the cable to be drawn over. Twisted or distorted pieces cannot be lined up and should be rejected. No duct with salt blisters or drips which project over 1/8 in. inside and pieces of conduit which may be air checked or fire checked should be rejected.

All duct should be tested for straightness with a mandrel of the length of the piece being tested and 1/8 in. smaller than the inside dimensions of the duct. If the mandrel will not pass, the duct should be rejected.

If the tile duct is properly vitrified, it will give a clear ringing sound when struck with a steel tool. A dead sound indicates softness and porosity. The results will be high breakage in handling, low insulation value, and the duct will absorb moisture.

Construction of the Single-tile Duct.—The pieces are laid end to end and are held in alignment during construction by the use of a wood mandrel at least 3 ft. long. The writer has used a 4-ft. mandrel and gets very good results with it. The size of the mandrel should be 1/4 in. smaller than the inside dimensions of the duct. Every joint should be wrapped with burlap or muslin dipped in asphaltum. A very good method used recently is to have the helper on top of the trench prepare each piece by painting both ends, wrapping muslin around them, and painting on the outside. This is handed down to the layer who lays it in the bottom of the trench on the 3-in. concrete base. The second piece handed to him is placed against the previous piece, the muslin wrapping is unfolded on top of the duct, and, after the

second piece is laid, the muslin is put back around the joint with the paint. The paint used for this is P & B, which sets very rapidly and holds the duct in alignment until the concrete is poured.

Fig. 34.—Helper on top of the trench preparing the conduit for the "layer."

Fig. 35.—Laying tile duct with 1½ inch separation.

Fig. 36.—Single tile duct construction using 1½ inch separation.

Figure 34 shows the helper on top placing the muslin wrapping. Figure 35 shows the method of laying tile duct with 1½-in. separation. The picture was taken on the surface to get detail. Figure 37 shows this act of laying length of 4-in.-tile duct.

Figure 38 shows the layer making a joint on single-tile duct. It is true many duct lines of single tile have been laid without wrapping joints, depending upon a mandrel with an eye on one end and a rubber gasket on the other to clean or drag ahead the cement or concrete which may leak through the joints. The cleaning period, however, is too short to accomplish this, as it takes from 12 to 24 hr. for the concrete to get its initial set. There is no telling how much concrete will leak into a joint as the mandrel is drawn ahead to lay the next and succeeding pieces

FIG. 37.—Layer in the act of laying a length of tile duct.
FIG. 38.—Layer placing muslin over joint.

of tile. The joints wrapped with muslin and P & B paint will not only stop concrete but keep out water. In order to get a tight joint with this method the manufacturer was asked to make the single tile without grooves on the exterior of the duct, leaving a clean, smooth, outside surface which saves time in painting.

The single-tile duct laid with 1½-in. separation of concrete mixed of 1:3:4 or 1:3:5 with good portland cement, clean sharp

sand and ½-in. rock with a 3-in. envelope of the same material makes a good construction.

There are problems, however, that must be considered with this construction. The usual procedure is to place a 3-in. concrete base in the bottom of the trench. It is necessary to allow this base of concrete to receive its initial set to allow the layer to walk on it without causing a great deal of unevenness in

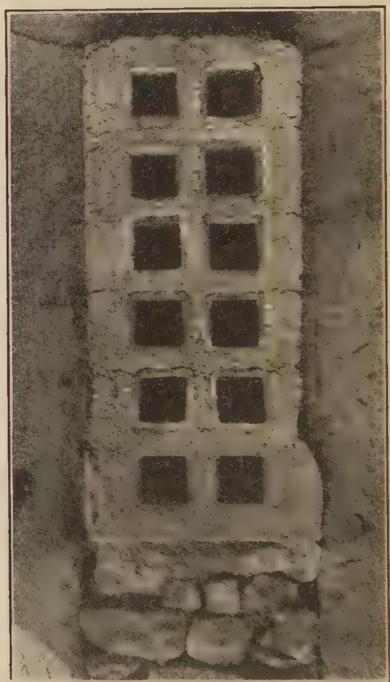


Fig. 39.—12 duct single tile laid tier by tier method.

the concrete. Then, the layer is able to get an even grade and straight line which is laid to a mason's line placed on the right side of the trench to line up with the top and the right-hand side of the duct surface, leaving 1½-in. separation between ducts.

After approximately 100 ft. are laid, the concrete crew will begin to pour concrete over the first layer of the duct. A gage is used on top of the duct to determine the proper thickness of concrete on top, which in this case would be 1½ in. This is tamped smoothly so that after the concrete has its initial set,

another crew of layers can begin the second tier. This system is carried out with all succeeding tiers.

The objection to this method, as with all conduit construction accomplished by the tier-by-tier method, is that there is the possibility of having a duct line consisting of several layers or slabs of concrete which are not bonded together (Fig. 39). Note the seams in the face of the duct showing each layer or tier.

The writer has worked out the built-up method with tile duct as well as with fiber duct. Figure 40 shows a test section of

FIG. 40.—A test section of single tile duct.

conduit built up and dismantled to discover voids in the concrete. Figure 41 shows the tile duct with concrete separation laid in the trench and 8 4½-in. square-bore ducts.

It is not necessary to tie tile duct with twine as described in the built-up method for fiber duct, as the heavy weight of tile will keep the duct line in place until concreting is completed.

It is necessary with the 1½-in. separation to pour concrete comparatively wet and to tamp carefully between ducts with a spade tamper. This method of laying tile duct gives a very satisfactory duct line and, with the concrete, forms a monolithic mass.

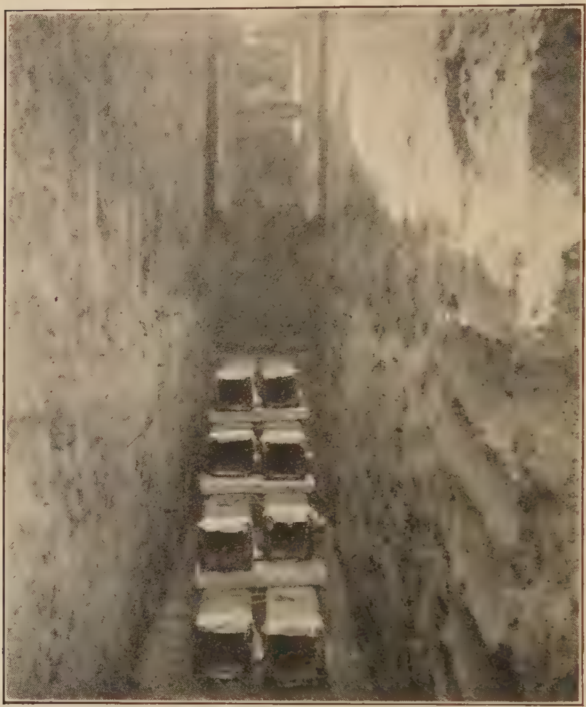


FIG. 41.—The built up method used with tile duct.

FIG. 42.—Single tile duct laid by an old method using one-half inch of mortar between ducts.

SPECIFICATIONS FOR COMMERCIAL A-GRADE, VITRIFIED-CLAY CONDUIT

The quality of the materials used and the methods of manufacture, handling, and shipment shall be such as to insure for the finished conduit the properties and finish called for in these specifications. The manufacturer must make sure that all material and work are in accordance with the specifications before the conduit is delivered.

The inspector for the purchaser shall have the power to inspect and reject any material or conduit before loading which fails to satisfy the requirements of these specifications, but such inspection by the customer at the factory shall be final.

General.—Conduits furnished under these specifications shall be single duct or two-, three-, four-, six- or nine-multiple duct, as specified by the purchaser.

Material.—All conduits shall be made of finely ground, compact clay, thoroughly vitrified, and shall be free from stones and pebbles. All conduits shall be uniform in size and quality.

The inspector for the purchaser shall be allowed to test for absorption the average run of conduits offered for shipment by completely immersing of average samples for twenty-four (24) hours in water at a temperature of from sixty (60) to eighty (80) degrees Fahrenheit.

Conduits showing an average absorption not over five (5) per cent to be accepted for shipment.

Dimensions.—The length of all conduits unless otherwise specified by the purchaser shall be as follows:

Single duct........................	eighteen (18) inches.
Two-duct multiple................	twenty-four (24) inches.
Three-duct multiple..............	thirty-six (36) inches.
Four-duct multiple................	thirty-six (36) inches.
Six-duct multiple..................	thirty-six (36) inches.
Nine-duct multiple................	thirty-six (36) inches.

Short lengths shall be furnished when called for. The number of pieces, however, shall not exceed one (1) per cent of the total number of duct feet ordered. All pieces less than one (1) foot long shall be paid for at the price of one (1) duct foot.

Diameter of Hole.—All duct holes shall be at least three and one-quarter ($3\frac{1}{4}$) inches in diameter, unless otherwise specified. Measurements of square duct shall be between parallel surfaces.

Wall.—The walls of all single conduits shall not be less than seven sixteenths ($\frac{7}{16}$) of an inch thick at their thinnest part.

The outer wall of all multiple conduits shall not be less than nine-sixteenths ($\frac{9}{16}$) of an inch thick at any part, and the inner walls or web shall not be less than seven-sixteenths ($\frac{7}{16}$) of an inch thick at their thinnest part.

Shape and Finish.—All conduits shall be reasonably symmetrical both on the outside and in the duct hole.

Ends and Corners.—The ends of all conduits shall be perpendicular to the sides. All duct holes shall be beveled at the ends. All ends shall be smooth and free from projections.

The interior corners of all duct holes and the exterior edges of the conduit (except the ends) shall be slightly rounded.

Alignment.—The duct holes for single conduits shall be well centered. A straightedge laid lengthwise on the concave side of the conduit three (3) feet in length shall not show an offset greater than three-eighths (3/8) of an inch, allowance being made for the scarification ridges at the ends. The allowable blow in short lengths shall be proportionate to the limit specified for three- (3) foot lengths.

Cracks.—Cracks in the walls of single-duct conduit shall not have an opening greater than one-eighth (1/8) of an inch at inner edge of bevel nor be over two (2) inches long.

Cracks in the outside walls of multiple-duct conduit shall contain through cracks at ends not exceeding four (4) inches in length or three-eighths (3/8) of an inch in width at inner edge of bevel.

Cracks in the inner walls of multiple-duct conduit shall not exceed six (6) inches in length, or three-eighths (3/8) of an inch in width at inner edge of bevel.

Blisters.—Single- and multiple-duct conduit shall not contain blisters or projections on the outer surface which project more than three-sixteenths (3/16) of an inch above the surface.

Single- and multiple-duct conduit shall not contain broken blisters or depressions which reduce the outside wall thickness in excess of one-fourth (1/4) of an inch.

Single- and multiple-duct conduit shall not contain blisters or projections on the inner wall surface which project above the surface more than one-sixteenth (1/16) of an inch.

Single- and multiple-duct conduit shall not contain depressions on the inner wall surface which show a recess of more than one-fourth (1/4) of an inch nor shall such depressions show a reduction of wall thickness greater than one-fourth (1/4) of an inch.

Single- and multiple-duct conduit that contains broken blisters or projections will be smoothed so as not to interfere with, or injure, the cable when drawn through the duct.

Scarifications.—The outer walls of the multiple conduits shall be scarified or otherwise suitably roughened on at least three (3) sides for at least two (2) inches at each end.

The outer wall of single conduits shall be combed with two (2) sets of three (3) combings each, running lengthwise on the conduit (and placed adjacent to the corners).

Glazing.—At least eighty-five (85) per cent of all conduits shall be thoroughly glazed. All conduits not thoroughly glazed on the inside shall be smooth, thoroughly vitrified, and shall meet the absorption requirements as before specified.

Dowel-pin Holes.—Unless otherwise specified, all multiple conduits shall be provided with at least two (2) dowel-pin holes. Dowel-pin holes shall be not more than sixteen thirty-seconds (16/32) of an inch nor less than eleven thirty-seconds (11/32) of an inch in diameter, and shall be located in the center of the intersection of the partition walls, and, when necessary, in the center of the intersections of the partition walls with the outside walls.

Dowel Pins.—Dowel pins shall be of a good grade of wrought or cast iron and shall be not less than three (3) inches long. Means shall be provided that will prevent the pins from slipping entirely into the dowel-pin holes of either section.

Packing.—Single and multiple conduit when shipped in cars shall be so packed that the ends and each layer shall be separated. The conduit shall be firmly braced at the doorway of the car to prevent shifting of load during transit.

Cleaning Ducts.—Just as soon as conduit line is completed between each two adjoining manholes, a mandrel 30 in. long and ¼ in. smaller than the bore of its conduit should be pulled through each duct and any obstructions found should be removed at once. If it is discovered that sand or clay was washed into the duct during construction it should be removed with a flue brush or any other means so that the duct will be clean before

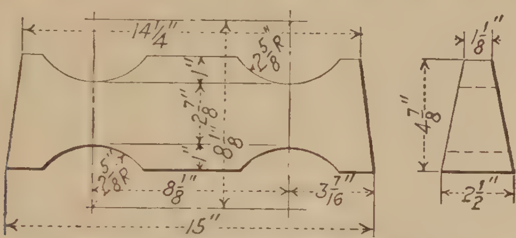


Fig. 43.—Grooved concrete separator.

cables are drawn in the duct. During construction and after the conduit is completed the ends of the ducts should be plugged to prevent water washing mud into ducts.

Service Ducts.—All ducts or service connections leading into a building, substation, or power house should be sealed around the cables as well as vacant ducts with oakum and portland cement, to prevent water or gas entering buildings.

Concrete Separators for the Built-up Method of Laying Conduit.—Three types of concrete separators have been developed: one grooved semicircularly to fit the fiber duct (see Fig. 43); one for the oblong or square-faced block, and one for the built-up method of laying tile duct which is made 1½ in. in thickness to approximately 6 in. wide and in various lengths to suit the number of tile ducts being laid.

The grooved separators are made in wooden molds. The molds are made to hold approximately from six to eight separators at one pouring. The concrete mixture consists of 1:1½:½

FIG. 44.—Grooved concrete separator moulds.

FIG. 44a.—Showing the built up method with square concrete separators. Note grade stake and separator in front.

portland cement, clean sharp sand, and chat (or stone which will pass through a sieve of ½-in. mesh). The mixture of concrete for separators is made comparatively dry and tamped into the wooden molds so as to press out as much water as possible.

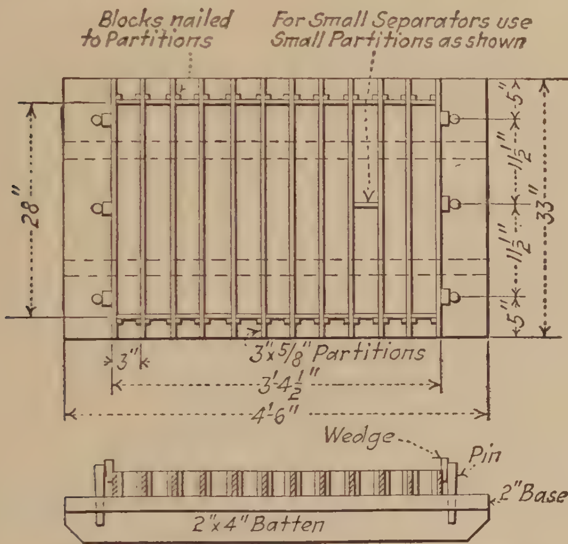


Fig. 45.—Moulds for square concrete separators.

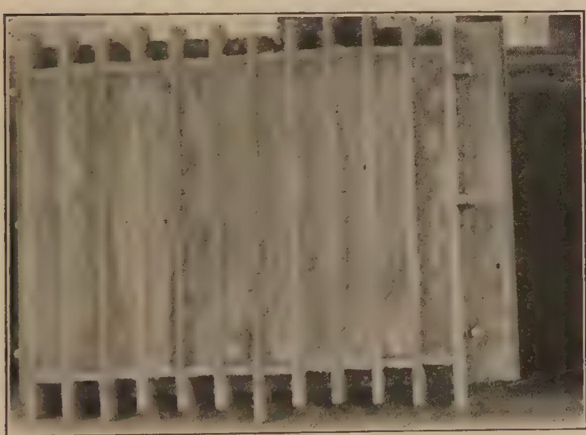


Fig. 46.—Showing the mould filled.

In dry weather the separators could be removed from the mold in 12 hr. and in wet weather in about 18 hr. They are removed by turning upside down and tapping the bottom of the mold

lightly. The separators are then piled and sprinkled with water twice a day for several days when they are ready for use.

Some trouble was experienced by the writer in removing separators from the mold due to not allowing enough time for the hardening and to the cement clinging to the wood. This

Fig. 47.—Shows how easily the concrete separators can be removed from mould by removing two wood wedges.

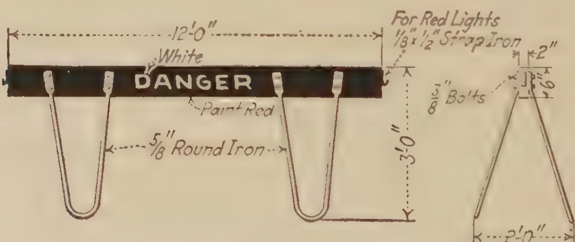


Fig. 48.—Trench barricade.

last trouble was overcome by applying soap and water to the molds with a brush before pouring. Molds and separators are shown in Fig. 44.

The square-faced or rectangular separators have been found through experience to be the better. They are less expensive to make. With the square-faced separators, full separation between the ducts is assured, while the grooved separators, the

ducts often ride the grooves and correct separation between the ducts is lost.

The manufacture of square-faced separators is very simple. Wooden molds as shown in Fig. 45 are provided if 3-in. separators are required. The concrete mixture is two parts of portland cement, three parts of clean, sharp sand, and three parts of clean stone that will pass through a sieve of ½-in. mesh. The mixture

Fig. 49.—Common telephone conduit construction practice.

should be made comparatively dry and must be tamped into the molds so as to press out as much water as possible. In dry weather, the separators can be removed from the molds in 12 hr., and in wet weather, in about 18 hr. The separators are removed by knocking out the pins and wedges and loosening the partitions and blocks. Figure 46 shows the molds filled with the separators and Fig. 47 shows how the separators may be taken out after the three wedges have been removed. If the separators stick

to the wood when being removed from the mold, the difficulty can be overcome by using a mixture of soft soap and water applied to the molds with a brush, before filling. After the separators have been taken out of the molds they are piled and sprinkled with water twice a day for several days in which time

FIG. 50.—Trench where single tile duct is being constructed.

they attain a hard set. Two men working 9 hr. a day can manufacture 300 separators, setting up the forms, mixing and tamping the concrete, removing the separators, and piling and sprinkling them with water.

Tile-duct Separators.—The rectangular slabs or separators used for the built-up method of single-tile duct are made in molds approximately the same as the square-faced separators.

CHAPTER IV

MANHOLE CONSTRUCTION

Manholes are usually built at intersections of streets or at bends in the street of conduit lines, to provide a place for splicing the cables. The distance between manholes depends upon the size of the cables and local conditions. In the past 500 or 600 ft. between manholes was not considered too long, but after 10 to 20 years of this practice it was found that cables drawn in at lengths of over 500 ft. received severe treatment, due to strain on the lead sheet and insulation, particularly in the case of multiple-conductor cables of high voltage, so that now 400 ft. is considered a good length between manholes. High-voltage cables, some of which have three conductors as large as 500,000 cir. mils, have called for larger ducts to accommodate the larger diameters and to allow for heat dissipation by ventilation. Increased concrete separation also has been found desirable and 3-in. separation has gone a long way toward solving some of the cable troubles.

In transmission systems it is desirable to limit the length to 400 ft. as this permits standard lengths of cable to be kept in stock, which can be used in any part of the system.

Manholes shoud be designed to suit local conditions. Manholes designed for high-voltage cables should be built large enough in proportion to the size of cables to be installed. In the case of high-voltage three-conductor cables, manholes should be long enough to avoid sharp bends. There should be very little bending at the point where the cable enters the manhole, on the racks which support the cable, and at the place where the splice is made. Great care should be taken to avoid change in duct elevation at manholes as this causes bends in the cable. Of course, such changes in elevation are sometimes tolerated on account of the extra expense necessary to avoid bends when manholes are situated near obstructions in the street. The added expense, however, is well justified as it will prevent possible future cable failures.

There are a great many types of manholes. They are: two-way, four-way, *L*-, *T*-, transformer, double manholes, and handholes. Manholes can be built of brick, concrete, cement blocks, brick walls with concrete tops, etc. The concrete manholes are easily built by common labor, with steel or wood collapsible

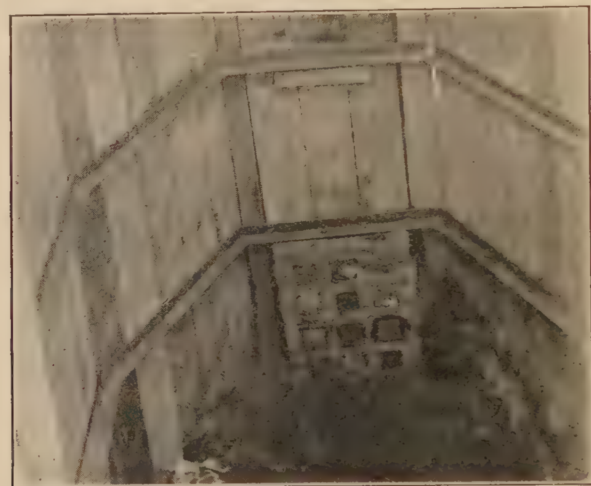


Fig. 51.—Angle iron brace for excavating manhole in sandy soil.

Fig. 51a.—Wood template for making manhole for excavation.

forms. All the manholes are constructed alike. The steel or wood forms save considerable labor.

Figures 52 and 53 are very good manholes for transmission cables. They will require very little cable bending. While Fig. 54 is long enough for small single-conductor and 3/0 three-conductor 13,200-volt cables, the 5½-ft. in width is excessive for

two ducts wide and will cause short bends in cables which should be avoided. When designing an *L*-manhole the problem of getting sufficient room in the street presents itself. When making a turn in a duct line, obstructions in the shape of water mains, gas mains, conduit, sewer, street-car tracks, etc. leave little room for the desired space. The *L*-manhole (Figs. 55 and 56) is

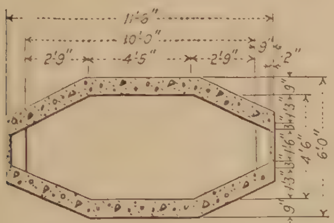


Fig. 52.—Octagonal manhole.

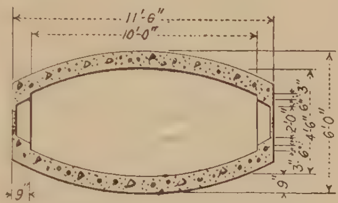


Fig. 53.—Elliptical manhole.

adaptable for this purpose and gives sufficient room for bending and splicing, while Fig. 57 is an expensive manhole from many points, high in cost, requires a great deal of space and necessitates bends in cables. The *T*-manhole can be built by using the *L*-forms and having an extra section *A-A* on the opposite side, or a very good *T*-manhole can be built as shown in Fig. 58.

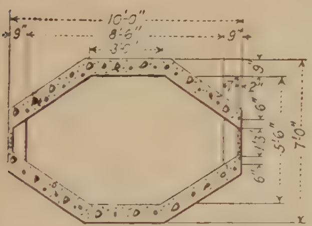


Fig. 54.—Short octagonal manhole.

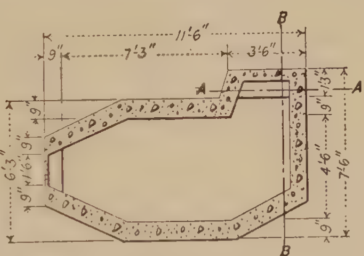


Fig. 55.—"L" manhole octagonal shape.

This *T*-manhole gives better racking space on wall *B-B* and sufficient racking space on wall *A-A*. While the width is no greater than would be necessary in using the *L*-forms at *B-B*, the difference will be in its length, but the excavation and concrete will be approximately the same. The cost, therefore, will be practically the same as when using the *L*-form.

The Length and Width of Manholes.—The length and width of manholes depends upon the kind of cable distribution designed and the number of ducts installed. For small d.-c. cables it is

not necessary to have a large manhole, but where there is a large number of d.-c. cables in one manhole, great care should be taken not to construct it too small. Plenty of wall space should be provided for racking and training cables around manholes without short bends. No bends should be made at the mouth of ducts. All cables should leave the duct straight, for at least 9

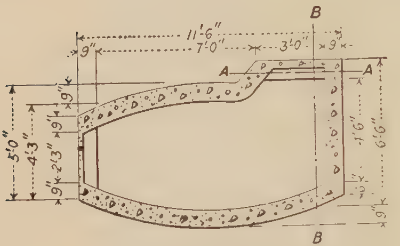


FIG. 56.—"L" manhole elliptical shape.

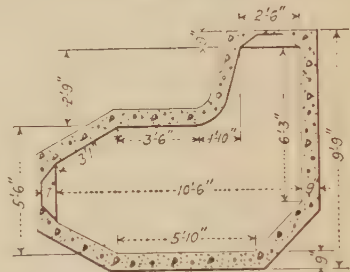


FIG. 57.—Short octagonal "L" manhole.

to 12 in. before bending. Abundant wall space should be provided for junction boxes, cut-outs, switch boxes, etc. Where junction boxes and other underground electric equipment are used in manholes the square manhole is most satisfactory. Attention should be given to duct entrances in manholes to avoid damage to cables while being installed. The bottom duct

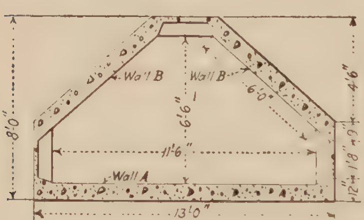


FIG. 58.—"T" manhole.

FIG. 59.—Plan of angle iron frame to support sheathing for excavating manhole.

should not be too close to the floor of the manhole nor the top duct too close to the roof.

Manhole covers should be located as near the center of the manhole as possible to avoid the chance of workmen using cables for a ladder. On the other hand, attention should be given to lining up the manhole cover with the duct entrance to insure easy entrance to the duct from the manhole opening without undue bending of cables while being installed. Eyebolts located in a

suitable place in the manhole wall opposite the duct are convenient for drawing in the cable.

All manholes should be properly drained and connected to the city sewer. An appropriate trap should be installed to keep out sewer gas. A backwater trap should be used where sewer water is likely to back up into the manhole. Where it is not possible to get a connection to the sewer a dry drain or thump hole may be provided by making an excavation 2 by 2 by 3 ft. in size with 4-in. concrete walls. This chamber should be filled with crushed rock or gravel. The top of the chamber should come flush with, or a little lower than, the floor of the manhole. A cast-iron grating should be placed over the chamber.

Manhole Construction in Sandy Soil or Water.—It has been said that concrete manholes are unwarranted in congested districts on account of the high cost of form work. It is claimed also that sandy clay which will not stand unless properly supported by bracing and contains water at a depth of 3 or 4 ft., makes it necessary to build brick manholes. Manholes for underground conduit, however, can be built of concrete under any of the above conditions as well as with brick, and at a lower cost. Figure 51 shows an angle-iron frame which is used for bracing sheet piling while a manhole is being excavated This frame can be laid on the surface of the paving at the location where the manhole is to be excavated and used for a template to mark the pavement for removal. This will give the proper dimensions and shape for the workmen to cut the paving. Figure 51*a* shows a wood template used for marking the pavement for manhole excavations. These can be made in various shapes. After the pavement and base are removed, excavation is begun to a depth of approximately 3 or 4 ft., then sheet piling is placed with the angle-iron brace in position. This brace is made in two pieces and is held together with machine bolts at each end with several sets of holes so that the width of the manhole excavation can be increased or decreased as desired. After the first angle brace is placed about 2 ft. from the bottom of the piling, another angle brace can be placed to hold the piling in place near the top. The bottom brace should be allowed to follow the piling to the maximum depth. More braces can be added at will as the work proceeds. Usually, two braces are sufficient for a manhole 8 ft. deep. No other bracing is necessary as this one gives freedom for the men to throw out the dirt as they

excavate, without the usual interference of timber bracing. The bracing is also convenient because it holds sandy soil in place.

If water is present in the manhole due to surface water or springs, gasoline-engine, electric-motor, or hand-driven pumps can be operated during the excavation and when the men are setting the forms. When the forms are set and ready for concrete, let the water rise to its natural level, then pour the concrete in the water using a spout or pipe behind the forms so as to deposit the concrete as near the bottom as possible, the spout to be raised as the walls progress. This method has been used successfully for years, and good tight walls have been obtained. In places where there are springs it is best to use steel reinforcing in the bottom or floor of the manhole.

MANHOLE CONSTRUCTION

After excavating for the manhole to its required depth, the sewer connection should be made after which the concrete floor or bottom is poured to a thickness of 4 or 5 in., draining toward a sewer trap. After the concrete is set, the forms are set up for the walls.

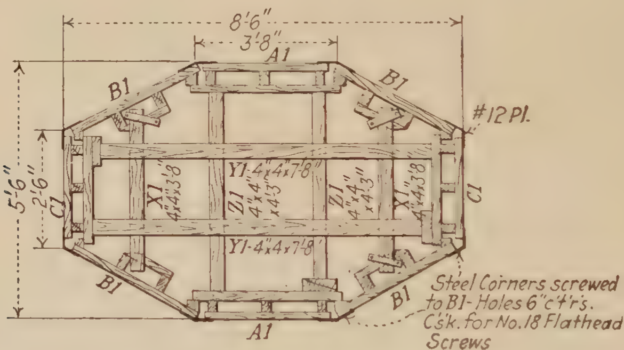


FIG. 60.—Plan of collapsible wood forms.

Forms for Concrete Manholes.—There are many types of forms in use constructed of wood and metal. The wood forms which are constructed for each manhole and torn out after the concrete sets are rather expensive and necessitate great waste of material. Where standard shapes can be used, collapsible wood or metal forms are economical. They can be used over and over again and will last for years. Figure 60 is a drawing of a collapsi-

ble wood form which has been used successfully. The various panels are built of 2- by 6-in. matched and dressed yellow pine. Cleats are of 2- by 4-in. and 2- by 6-in. yellow pine. The corners are covered by steel plates bent to the proper angle, one edge of which is screwed to the panel with 1¼- by 16-in. wood screws. The bracing for holding the forms in place while the concrete is being poured consists of 4- by 4-in. yellow pine. Two braces are clamped in place by iron clamps made up of 2¼- by ⅜-in. bar iron cut in 7-in. lengths with two ¾-in. holes. The other braces are held in place by wood wedges.

The procedure for erecting forms is as follows:

1. Place corner forms $B1$.
2. Clamp struts $X1$ in place. Get $X1$ at right elevation to make struts $Y1$ butt against 2- by 6-in. stringers of forms $C1$.

FIG. 61.—Showing bar reinforcing and ring form for entrance.

FIG. 62.—Collapsible wood forms in place.

FIG. 63.—Collapsible wood forms in place, for "L" manhole.

3. Place forms $C1$ and struts $Y1$. $Y1$ rests on top of $X1$.
4. Place forms $A1$ and struts $Z1$. $Z1$ rests on top of $Y1$.
5. Block in between studs of adjoining forms.

The forms are for a manhole of 6½-ft. head room. If a greater depth is required, the forms can be raised for a greater depth after the first pouring of concrete has set. Holes can be arranged at each end of the form for eyebolts to be used for pulling cable. Provision can be made for setting bolts for cable racks. Most cable racks require but two bolts, and the labor of installing them after the walls are completed is so small that it hardly pays to set cable-rack bolts before pouring the concrete. The roof or

top of manhole forms can be made of 2- by 6-in. or 2- by 2-in. yellow pine with a hole in the center so that men can enter to remove the forms later. (See Fig. 61, showing reinforcing of

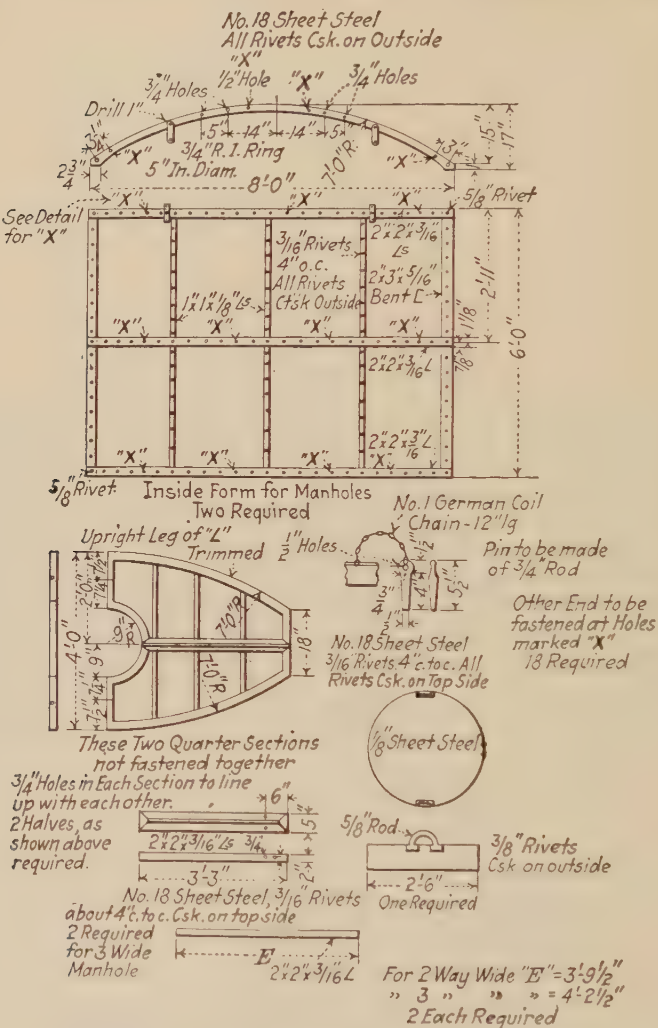


Fig. 64.—Working drawings for steel manhole forms.

the top forms and ring.) Figure 62 shows wood collapsible forms in place ready for the concrete walls. Figure 63 shows wood collapsible forms in place for an L-manhole. The wood forms are heavy and require continual repairing and painting.

The labor required for setting up collapsible wood forms is considerably lower than that for a carpenter-built form.

Steel Collapsible Forms.—The oval manhole is the most simple to construct, due to its shape. Steel collapsible forms can be constructed in four pieces for the walls, two sides and two ends. Figure 64 is a working drawing of steel forms developed by the writer and used successfully for years in constructing manholes. These forms can be dropped into a manhole excavation, set up, and bolted together in 1 hr. ready for concrete.

The forms consist of No. 18 sheet steel reinforced with 2- by 2- by 3⁄16- or 5⁄16-in. angle iron riveted together. The inside ribs are 1- by 1⁄8- or 1⁄4-in. angle iron which should be riveted and spot welded. All corners should be spot welded. Rings are placed in the top angle for handling. The forms are held rigid by three braces consisting of two angle-iron pieces, placed crosswise at the center of the forms with bolts at each end and center, and located at bottom, center, and top (Fig. 65).

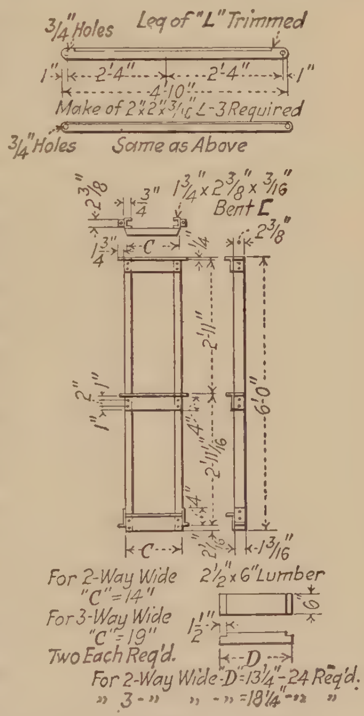


Fig. 65.—Bracing and end frames for forms.

The end forms are angle iron and channel frames made to receive boards which can be dropped in from the top. These boards are made movable so that they can be adjusted to accommodate any elevation of duct entering the manhole. The end forms are made in two or three widths for manholes of different widths. The roof or top forms are made of steel, as shown, in four quarter sections. There are additional small panels made for the top forms to take care of manholes two, three, or four ducts wide.

Figure 66 shows an angle-iron form or brace for wooden sheeting. One or two are required depending upon the depth of the manhole.

Figure 67 is a cross-section showing steel forms in place for a two-way-duct manhole. Note the cross-bracing of angle iron holding the forms in place and 2- by 8-in. wood sheeting in place for use in sandy soil or when water is present. Note the end forms and the bell mouth for the duct entrance to the manhole. This bell mouth is made by pouring concrete to the elevation of duct, then a man reaching down at the end of the manhole can

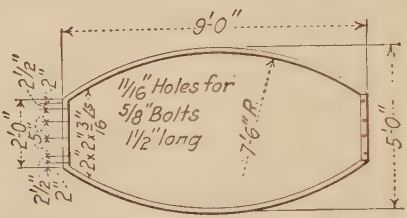


Fig. 66.—Angle iron brace for wood sheathing.

trowel the bottom of the bell mouth. Two pieces of sheet steel about 6 in. wide and as long as the bell mouth are placed on each side of the form. The space between these two plates is filled with sand, the ducts having been stopped up with wooden plugs to prevent sand or concrete entering. The sand makes the core for the bell mouth (for sand core or mold see Fig. 67). The concrete mixture for walls should be in the proportion of 1:3:5

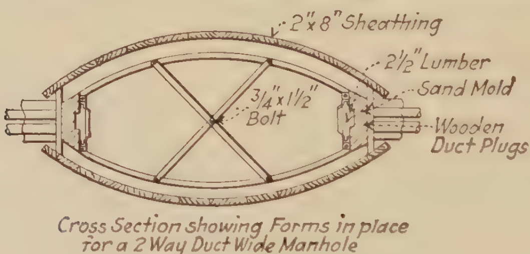


Fig. 67.—Steel forms in place showing sheathing ready for concrete.

of portland cement, clean sharp sand, and 1- to 1½-in. rocks. Concrete mixture for the top or roof of the manhole should be in proportions of 1:2:4 using portland cement, clean sharp sand, and 1-in. rock. The thickness of walls should depend on their length and height. The same conditions influence the thickness of the roof slab.

Pouring Concrete for Manhole Walls.—When using angle-iron forms for bracing wood sheeting or piling, the first or lower

brace will be located about 2 ft. from the bottom of the manhole. When concrete is being poured for walls, it should be poured up to the bottom brace. This brace can then be removed. The concrete if properly mixed will hold the sheeting in place. Pouring the concrete can then be resumed until the top brace is reached. This brace should be left to brace against paving until the concrete has had at least 24 hr. to set. The wood sheeting or piling can be withdrawn as explained in driving and removing bracing.

Great care should be taken while pouring concrete for walls. One or two men should tamp the concrete with a spade tamper, the blade of tamper being continually run down the surface of forms to insure smooth and tight walls.

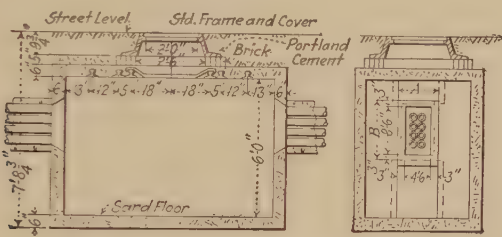


FIG. 68.—Elevation of manhole.

After the walls have been poured, sufficient time should be given for the concrete to set before the forms are removed. From 48 to 72 hr. should be allowed, depending upon the temperature, weather, and nature and condition of soil. If springs are present in the manhole excavation more time should be allowed.

Figure 68 shows the elevation of an oval-shaped concrete manhole for eight ducts. This manhole is without concrete bottom, or sewer connection. This construction can be carried out successfully in sandy soil where there are no springs. However, the concrete floor and sewer connection can be constructed if necessary. The roof is designed to use 5-in. 80-lb. rail for reinforcing and special bent bars with hooks on each end as shown. One course of brick was laid before the casting was set so that the casting could be lowered in the future. This is a good plan in streets where there is no paving. When paving is put in later it is possible to change the grade. It is not intended to specify old railroad iron for reinforcing in manhole tops, but

most railway companies have old worn rails which can be used by them at low cost. If rails are used for reinforcing, great care should be taken to cover them completely with concrete so that no parts of the rails are exposed to air inside of the manhole.

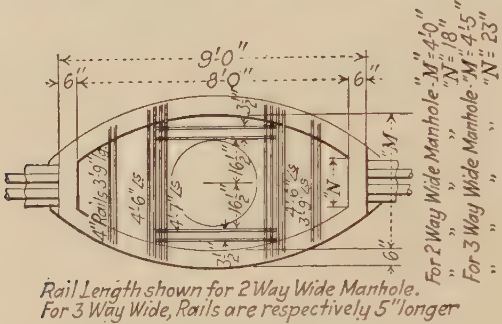


FIG. 69.—Plan of reinforcing.

This will prevent rusting. The useful life of steel exposed in manhole tops is from 10 to 15 years. Figure 69 is a plan of the reinforcement of the concrete top with steel rails and special bent bars.

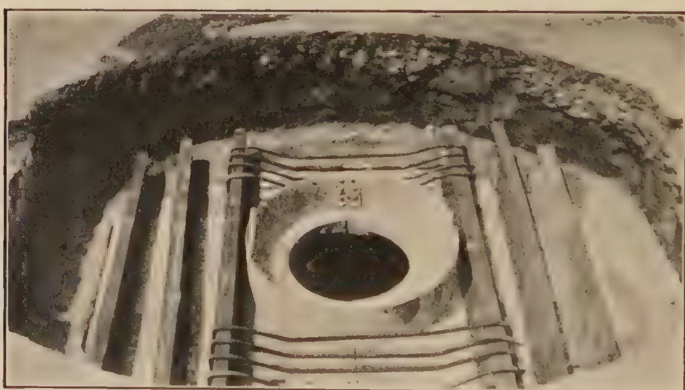


FIG. 70.—Showing manhole top steel rail reinforcing for concrete.

Figure 61 is another type of reinforcing for concrete tops consisting of $\frac{3}{4}$-in. deformed steel bars. These concrete slabs or tops are 8 in. thick.

After walls have set for 48 to 72 hr., the wall forms can be removed and the roof forms put in their place. Reinforcing

steel is then placed on the forms together with manhole ring form. Figure 61 shows top forms, ring and reinforcing in place. Figure 70 shows an oval-shaped manhole with old railroad iron in place for reinforcing and ready for concrete. Note the roof forms are steel. In Fig. 61 the roof forms are 2- by 10-in. yellow pine.

Fig. 71.—Short set of steel forms. This form is moved up as walls are poured.

Avoid Pipes.—Gas, water, steam, or sewer pipes should be avoided when constructing manholes. If the conduit and manholes cannot be built so as to avoid them, they should be cut around manholes wherever possible. Gas mains are very dangerous in manholes. A leaking joint is likely to cause great damage to

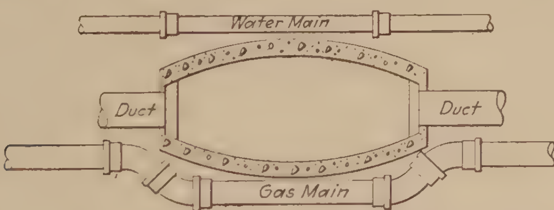


Fig. 72.—Cutting gas main around manhole.

life and property. Many fires have occurred from leaks in gas mains where numerous cables were involved. If it is impossible to keep them out of manholes they should be covered with some good fireproof material. Expanded metal can be placed around the pipes with a ½-in. separation between the pipe and expanded

metal. Cement mortar is then applied about 1 in. thick. This will prevent gas from leaking into the manhole and also protect the pipe from possible short-circuit flashes. The best plan, however, is to have the pipes cut around the outside of the manhole walls. The manhole walls should not be allowed to rest on the pipes, as the manhole may settle and cause a break in the pipe.

Figure 72 shows how the pipes can be cut around outside of the manhole walls.

Double Manhole.—To separate the high-voltage cables from the low-voltage cables two or more duct lines are constructed with separate manholes, or one duct line with double manholes separating the ducts as they enter the manholes. Figure 73

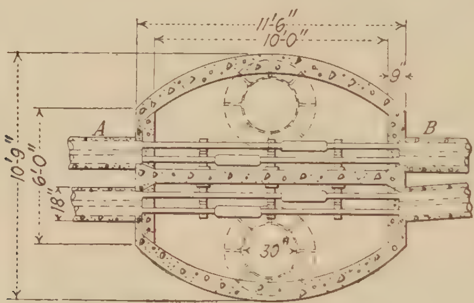


Fig. 73.—Double manhole.

shows a double manhole with divided duct lines. The cables can be racked on straight walls getting good separation in the manholes.

Figure 73 shows a double manhole with a 6-in. concrete wall separating the two manholes, the cables to be racked on the straight walls eliminating bends in cables. This manhole is of generous length and allows for staggering splices. The two duct lines can be installed in one trench with 9-in. separation between the two duct lines as in *A*. The 9-in. space is to be backfilled with clay. Another formation for duct lines entering manholes is shown in *B*. With this plan the two duct lines run together about 30 ft. from the manhole. The plan *A*, however, is considered the best because of the separation between the two duct lines, building only two wide and five high, thus making a narrow section giving better radiation of heat and bringing the cables into manholes straight without bends.

The cost of a duct line and manholes as described is considerably cheaper than that of building two separate duct lines, one on each side of the street, or on the same side of the street. It is true that considerable space is required for this plan and it may not be practical in congested districts. This plan, however, gives all that can be desired for long cable life and continual service between power house and substations.

Transformer Vaults.—Where transformers are operated underground, separate manholes or vaults are constructed. The size of the transformer vaults depends upon the size of the transformer and the number of distribution cables. Great care should be taken to provide a good drain for water so as to keep the vault as dry as possible. The ventilation of transformer vaults is

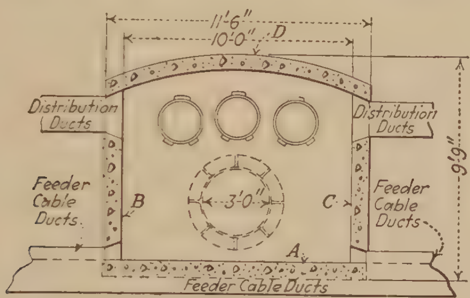


FIG. 74.—Transformer vault or manhole.

very important. Two vent pipes of ample size should be provided, one near the bottom of the vault at one end and one near the roof at the other end, to prevent short-circuit of the air currents. There should be allowed from 3½ to 4 cu. ft. of space per kva. of transformer capacity.

Figure 74 shows a transformer vault with two distinct and separate duct lines, one for feeder cables and the other for distribution cables. The ducts for feeder cables are partly built in wall *A*. All the ducts on the side toward the vault open into it, leaving a single vertical duct line for the number of ducts required for the immediate and future load demand. The remainder of the ducts goes through to be used for feeding other vaults or substations. Walls *A*, *B*, and *C* are reserved for racking feeder cables. A loop or double feeder-cable system can be used with this arrangement successfully. The *D* wall is reserved for racking distribution cables, cut outs, and other apparatus in

this connection. Eyebolts should be placed in the walls to take care of pulling cables and moving transformers.

MANHOLE CASTINGS

Manhole castings should be made of good, clear, gray cast iron, and covers should have sufficient strength to withstand at

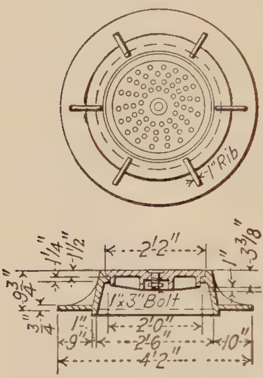


Fig. 75.—24 inch cast iron manhole cover.

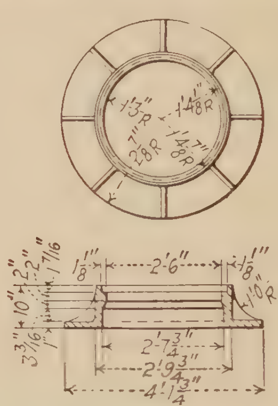


Fig. 76.—30 inch cast iron manhole cover.

least 15 to 20 tons. A standard casting should be adopted so that as small a stock as possible can be kept on hand for maintenance purposes. The round cover is most practical. It is

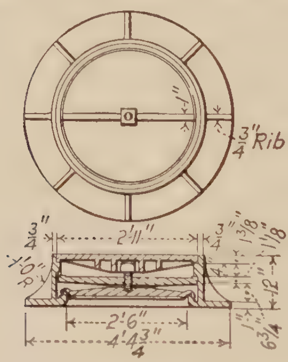


Fig. 77.—36 inch cast iron manhole cover, water tight.

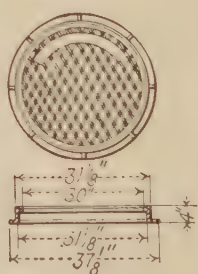


Fig. 78.—30 inch cast iron sidewalk manhole cover.

easily removed and replaced without danger of slipping into the manhole and damaging cables, as is possible with square or oval covers. Each casting should be inspected before it leaves the

foundry, for sand holes, flaws, etc. Each cover should be mated to a frame by grinding to avoid rocking of the cover. This is very annoying to the public and is very noticeable under automobile traffic. After a cover and frame are mated they should be marked in some suitable manner to prevent separation in the process of delivery to the construction field. The minimum opening should not be less than 24 in. Where transformers and junction boxes are used, it is necessary to have larger openings. Figure 75 shows a 24-in. manhole frame and cover. This cover

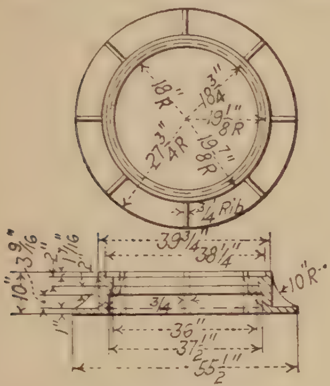


FIG. 79.—36 inch cast iron manhole cover.

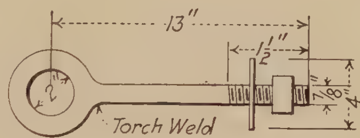


FIG. 80.—Eye bolt to build in manhole wall for pulling cable.

is large enough for manholes with small cables. Figure 76 is a 30-inch frame and cover and is a good standard manhole cover which can be used on almost any manhole. Figure 77 is a 36-in. water-tight manhole frame and cover with an inner cover to prevent water entering from the top. Figure 78 is a 30-in. sidewalk or station-type manhole frame and cover. Figure 79 is a 36-in. manhole frame and cover for manholes with transformers, junction boxes, etc.

Figure 80 shows an eyebolt to be installed in manholes for pulling cables. The eyebolt with a nut has the advantage of easy removal. When portable forms are used, after the concrete is thoroughly set the eyebolt can be screwed out to allow removal of the forms after which it can be screwed back in place. On the other hand, if a bolt with a hook is used, a large hole is necessary in the forms so that they can be removed.

CHAPTER V

UNDERGROUND CONSTRUCTION COST DATA

Safe estimates on underground-conduit construction are made only by getting costs from actual construction jobs as they proceed. Therefore a simple method of collecting this information is necessary.

UNDERGROUND CONSTRUCTION REPORT

CHARGE TO W. O. 6640

Excavating Trench

LOCATION

From Forest To Troost

On 11th Street

M.H.893 To M.H.894

Kind of Excavation Clay Date 7/24 1924

Depth	Width	Length	Wall	Bottom	Top	Cover
3'	20	316'				

Men	Rate	Hours	MATERIAL
3	45¢	21	Cement
52	40¢	292½	Crushed Rock
			Sand
			Brick
			Separators
			Kerosene 3 gallons
			Gasoline
			Oil
			Kind of Paving Brick

REMARKS:

Foreman.

Fig. 81.—Field construction report "excavating."

Experience teaches that there are no two jobs exactly alike. Every job has its own peculiar conditions. Estimates made in the office without knowledge of the local conditions in the field,

either from investigation or past experience, are merely guess work. A complete study should be made in the field by getting the locations of all gas mains, water mains, conduits of the various companies, steam mains, sewers, etc. Some of the companies or city officials may be able to furnish valuable information in regard to the depths, and kind of soil or rock.

UNDERGROUND CONSTRUCTION REPORT

CHARGE TO W. O.	LOCATION
Pouring Concrete For Conduit.	From 10th Street To 11th Street On Forest. M.H 892 To M.H. 893

Kind of Excavation.. Date.......................................192....

Depth	Width	Length	Wall	Bottom	Top	Cover
35"	20"	110'				

Men	Rate	Hours	MATERIAL	
2	45¢	7	Cement	54 sacks.
15	40¢	53	Crushed Rock	15 cubic yards.
			Sand	7 cubic yards.
			Brick	
			Separators	
			Kerosene	
			Gasoline	4 gallons.
			Oil	$1\frac{1}{2}$ quarts.
			Kind of Paving	

REMARKS: Crossed one entersection. 2-10' tunnels.

.... Foreman.

FIG. 82.—Field construction report "pouring concrete."

It is necessary to keep a very complete record of every operation each day. This record will become a factor in future estimates and appraisal work because it furnishes a progress report each day or week, including labor in man-hours.

Construction Reports.—Figures 81 to 82 are typical construction reports, used by the writer for over 10 years, to get the information required for cost data and progress reports. This report is made as simple as possible so that the foreman or his timekeeper has very little writing to do, as all the headings are printed.

Conduit Const

						Removing Pavement				Excavation					Running Concr'te			Materials Used			Cost of Materials Used			
							Labor				Labor													
From M.H. No.	To M.H. No.	No. of Ducts Size Kind	Date Finsh	Total Lngth	Net Lngth	Sq yd	Total Hrs.	Men	Total Cost	C U. Yds	Total Hrs.	Men	Cost	Cu. Yds. Cncr't	Total Hrs.	Men	Total Cost	Cmnt Sacks	Rock Yds	Sand Yds.	Cm'nt	Rock	Sand	Tr'n Fe

FIG. 83.—Detail office

Manhole Const

			Removing Pavement Labor				Excavating				Concreting			Material Used			Cost Material Used			Setting Forms			Setting Castings			Re
Location of M.H.	M.H. No.	D'pth Ft.	Sq. Yds.	Total Hrs	Men	Total Cost	Cu. Yds	Total Hrs.	Men	Total Cost	Total Hrs	Men	Total Cost	Cm'nt Sacks	Rock Yds.	Sand Yds.	Cement	Rock	Sand	Total Hrs	Men	Total Cost	Total Hrs.	Men	Total Cost	Tot Hrs

FIG. 84.—Detail office

The method of using these reports is to fill out one sheet for each class of work. Figure 81 is for excavating. The seven squares labeled "depth," "width," "length," "wall," "bottom," "top," and "lower" can be used for conduit and manhole construction. The first three squares can be used for excavating trench or for manhole construction only. The column headed "material" is used each day so that an accurate check may be had on the amount of material used in each section between manholes. In this report it will be noted that a trench was excavated 3 ft. deep, 20 in. wide, in 313½ man-hr. The material used was 3 gal. of kerosene for red lights at night.

Figure 82 is not a complete record of the conduit concreted in section 892 to 893, but the following day another report is made out until the duct is completed in this section. Other report sheets are made out on similar sheets for laying conduit, removing paving, excavating manholes, concreting walls, hauling material, etc. The foreman's time is prorated over the different operations each day.

The reports are sent to the superintendent's office where the cost-data clerk enters them in their respective places on the large cost-data sheets. Figure 83 shows conduit construction data, and Fig. 84, manhole construction data.

When the construction job is completed, a recapitulation is made of the large sheets. Figures 85, 86, 87 and 88 are typical recapitulation sheets for conduit and manhole construction. Besides the cost data, every day a complete log is kept on each job giving weather conditions, kind of paving, soil or rock excava-

tion Cost Data

duit		Back Fill			Cost of C'nd't	Pav- ing Bill	Removing Surplus Dirt					Total Cost	Hauling Material					Total Cost	No. of C'ncrt Bl'cks Used	C'ncrt Bl'cks (Sep- er)	Gas Paint Tape Etc.	Night Watn & Box- Man	Cost of Per- mits	Un- dis- trib- uted Lab'r	Total Cost
							Truck		Labor				Truck		Labor										
n	Cost	Total Hrs.	Men	Cost			Total Hrs.	Cost	Total Hrs	Men	Cost		Total Hrs.	Cost	Total Hrs.	Men	Cost								

record, conduit.

tion Cost Data

	Miscellaneous			Backfilling			Sewer Connections			Cost of Sewer Pipe and Trap	Cost of M H. Frame and Cov'r	Hauling Material				Hauling Dirt					Pav- ing Bill	Removal			Steel Used	Cost of Steel
												Tr'ck	Labor			Cu. Yds.	Truck	Labor								
al s	Total Hrs.	Men	Total Cost	Total Hrs	Men	Total Cost	Total Hrs	Men	Total Cost			Total Hrs	Total Hrs.	Men	Total Cost		Total. Hrs.	Total Hrs.	Men	Total Cost		Total Hrs.	Men	Total Cost		

record, manholes.

tion, reason for extra depth or extra width, accidents and other valuable information which is necessary to show local conditions of the job so that comparisons can be made on future work or estimates.

The following is the cost and construction data of actual installations of conduit and manholes. This cost data is represented in man-hours and cost, so that it can be compared easily with any other underground-conduit installation costs.

Analysis and cost of labor of a four-duct underground conduit, consisting of 17,345 duct ft. or 4,336 trench ft. of 3½-in. socket-joint fiber duct. Labor, 10 hr. Weather conditions, good and no interruptions.

Excavation.—This line was constructed just ahead of street paving. All surface and foundation material had been excavated by the paving contractors. The trench was excavated so there would be a minimum of 30 in. between the top of the duct structure and the finished surface of the street. The trench soil was loose sand that could be shoveled without picking.

Sheathing.—It was necessary to brace and sheath 689 ft. of trench. This was done in 320 man-hr., or at the rate of 0.4644 man-hr. per trench foot.

Laying Conduit.—The conduit was laid by the built-up method, using 1-in. square wooden separators. The joints of the conduit were painted with P & B compound No. 2.

Concrete.—The concrete mixture was 1:7, portland cement and torpedo sand. Mixing was done in a ¼-yd. mixer. The greater part of the sand used in the concrete was taken from the trench.

Surplus Earth.—Company work cars hauled away the surplus earth at night; the average haul being about 15 miles.

Hauling Material.—Company work cars and trucks were used for hauling all materials to the job.

Miscellaneous.—This line of conduit coincided with an old limestone gutter which had to be removed for a distance of 400 ft. This was charged to excavation. Manholes were excavated to comply with the shape of manhole which was oval (see Figs. 68 and 69). A steel angle form was used and sheeting was driven to hold back loose soil and sand. Steel forms of four pieces were dropped inside of the sheeting and concrete was poured. The size of manholes was 4 by 8 by 4½ ft. No bottoms were put in the manholes. The soil being sandy, the water would drain through the soil.

ANALYSIS AND COST OF LABOR OF A FOUR-DUCT UNDERGROUND CONDUIT
JOB NO. 1

Duct feet	17,345.0 ft.
Trench feet	4,336.0 ft.
Conduit installed	3½-in. socket-joint fiber conduit
Concrete mixture	1–7 portland cement and torpedo sand
Concrete envelope	3 in. all around 1-in. separation
Common labor	10 hr., 20 cts. to 25 cts. per hour.

MAN-HOURS

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Labor miscellaneous	....	80	0.01845	0.00461
Labor excavating	1.28	1,650	0.3805	0.09513
Labor mixing and pouring concrete	3.36	1,080	0.249	0.06226
Labor laying conduit	....	334	0.077	0.01926
Labor backfilling	.89	770	0.1776	0.04439
Labor removing surplus dirt	3.58	366	0.0844	0.02110
Labor placing sheeting (689 ft.)	....	320	0.0738	0.01845
Labor handling material	....	343	0.0791	0.01977
Labor hauling material, construction car and truck service	3.78	200	0.0461	0.01153
Total	....	5,143	1.18595	0.29650

MISCELLANEOUS DATA CONDUIT

Item	Totals	Per trench foot	Per duct foot
Excavation, cubic yards	1,284	0.29613	0.07403
Materials used, cement, bags	1,006	0.23201	0.058
Materials used, sand, yards	330	0.07611	0.01903
Surplus dirt removed, cubic yards	102	0.02352	0.00588
Number of manholes	8	0.00185	0.00046
Average section length, feet	500	0.11531	0.02883
Approximate amount of concrete used, cubic yards	321	0.074003	0.01851

Approximate cost materials, per cubic yard of concrete	$1.88
Approximate cost labor, per cubic yard of concrete	1.37
Total	$3.25

Cost of Manhole Construction in Connection with a Four-duct, Fiber-conduit System

Job No. 1

Number of manholes....	8
Conduit installed.......	3½-in. fiber socket joint.
Concrete mixture.......	1–7
Common labor.........	10-hr. day. 20 to 25 cts. per hour.

Man-hours

Item	Per cubic yard	Total hours	Per man-hole
Labor excavating and placing sheeting.......	6.5	104	13.0
Labor placing and removing forms...........	...	42.4	5.3
Labor mixing and pouring concrete..........	9.0	200	25.0
Total..................................	...	346.4	43.3

Miscellaneous Data—Manholes

Item	Total	Per manhole
Excavation cubic yards.....................	24	3
Material used, cement, bags................	48	6
Material used, sand, yards.................	24	3
Approximate amount concrete used, cubic yards	22.4	2.8
Approximate cost of materials per cubic yard of concrete............................	....	1.22
Approximate cost of labor per cubic yard of concrete............................	....	2.41
Total..................................	....	3.63

NOTES ON THE CONSTRUCTION OF A SIX-WAY 3½-IN. FIBER-CONDUIT LINE

Number of actual working days, 17.

Excavation.—This conduit line was constructed prior to paving the street, that is, all surface and foundation material had been excavated so that it was unnecessary to remove old paving and an equivalent of 1-ft. depth of excavation. The earth in which the conduit was laid was loose sand and clay loam, which could be shoveled without picking except a strip of old roadway 2 ft. wide, 677 ft. long, and 26 in. thick which was very hard and had to be picked.

Sheeting.—For a distance of 371 ft. the trench had to be excavated to a depth of 6.5 ft., requiring two sets of sheeting, on account of crossing a telephone conduit at two points.

Obstructions.—The telephone conduit had to be supported in stirrups for a distance of 60 ft. The conduit also had to be run under a telephone manhole.

Laying Conduit.—A 2-in. layer of concrete was deposited on the bottom of the trench, then two ducts were laid with a 1-in.-square vertical separator between them. A 1-in.-square horizontal separator was placed on top of the two ducts and two more ducts on top of the separators, and so on, until six ducts were in place. The ducts were held in place by two pieces of heavy twine to every 5 ft. of trench. After the conduits and separators were tied in place the trench was filled with concrete until there was a 3-in. concrete covering over the conduit. The joints of the fiber conduits were covered with P & B paint.

Concrete.—The concrete was mixed with a ¼-yd. Buffalo mixer. The concrete was conveyed to the trenches and manholes in wheelbarrows.

Hauling Material.—Part of the sand was received from company work cars. The balance of the sand required was taken from the trench.

Surplus Earth.—The disposal was hauled by team, furnished by a property owner wanting filling. Average haul, 500 ft. The balance was hauled by the company's motor truck. Average haul, 2,000 ft.

Miscellaneous.—The motor truck had to stand on the street-railway company's paved right of way on account of the street being too soft to support it. The truck had to clear the track

for passenger cars, which maintained about a 5-min. service. Manholes were excavated to comply with the shape of manholes which were oval. A steel angle was bent oval and sheeting was driven to hold back loose dirt or sand. Steel forms of four pieces were dropped inside of the sheeting, and concrete was poured. The size of the manholes was 4 by 8 by 4½ ft.

ANALYSIS AND COST OF LABOR AND MATERIAL OF A SIX-DUCT UNDERGROUND CONDUIT INSTALLED IN 1914, JOB NO. 2

Duct feet	12,618.0
Trench feet	2,103.0
Conduit installed	3½-in. socket-joint fiber conduit
Concrete mixture	1–7 portland cement and torpedo sand
Concrete envelope	3 in. all around 1-in. separation
Common labor	10 hr., 20 to 22½ cts. per hour

MAN-HOURS

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Miscellaneous labor	....	63	0.03	0.005
Labor excavating	1.64	1,166	0.5545	0.0924
Labor mixing and pouring concrete	3.94	810	0.3852	0.0642
Labor laying conduit	....	301	0.1431	0.0238
Labor back filling	1.05	490	0.233	0.0388
Labor removing surplus dirt	1.27	131	0.0623	0.01038
Labor placing sheeting (1,322 ft.)	....	640	0.3043	0.0507
Labor handling material	....	237	0.1127	0.0188
Labor hauling material, construction car and truck service	0.30	100	0.04755	0.0079
Total	....	3,938	1.87265	0.31198

LABOR COSTS

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Cost of excavating	$0.36	$258.00	$0.123	$0.02045
Cost of mixing and pouring concrete	0.886	180.78	0.086	0.0143
Cost of laying conduit	......	67.84	0.032	0.0053
Cost of backfilling	0.23	110.25	0.053	0.0087
Cost of removing surplus dirt	0.29	29.53	0.014	0.0023
Cost of placing sheeting (1,322 ft.)	......	145.06	0.069	0.0115
Cost of handling material	......	53.42	0.026	0.0042
Cost of hauling material, construction car and motor-truck service	0.29	100.00	0.047	0.0079
Miscellaneous labor	......	14.30	0.006	0.0011
Total	......	$959.18	$0.456	$0.07575

FIG. 85.—Typical recap sheets.

MATERIAL COSTS

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Cost of cement (per bag)	$1.248	$ 274.62	$0.13	$0.022
Torpedo sand	0.458	100.00	0.047	0.0079
City permits	0.030	6.00	0.0028	0.0005
1 by 1-in. wood strips at 1 ct. each	....	4.00		
Twine No. 6 at 0.075 per pound	....	2.40		
P & B paint (4 gal. at $1.12)	....	4.48		
Gasoline at 12 cts	0.0025	1.80	14.22.0076	0.0011
Kerosene at 0.04 ct	....	0.42		
Motor oils at 28 cts	0.00168	1.12		
12,618 ft. of 3½-in. fiber duct at 0.0484 ct.	....	610.72	0.29	0.0484
Total	....	$1,005.56	$0.47656	$0.0799

TOTAL COSTS

Item	Totals	Per trench foot	Per duct foot
Total labor cost	$ 959.18	$0.456	$0.07575
Total material cost	1,005.56	0.4765	0.0799
Total	$1,964.74	$0.9325	$0.15565

MISCELLANEOUS DATA

Item	Totals	Per trench foot	Per duct foot
Excavation, cubic yards	709	0.3371	0.056
Material used cement, bags	698	0.331	0.0553
Material used sand, yards	210	0.099	0.016
Remove surplus dirt, cubic yards	104	0.0494	0.0082
Number of manholes	5		
Average section length in feet	500		
Approximate amount of concrete, cubic yards	220		

Approximate cost of material	$1.70
Approximate cost of labor	0.89
Total	$2.59

FIG. 86.—Typical recap sheets.

COST OF MANHOLE CONSTRUCTION IN CONNECTION WITH SIX-DUCT FIBER-CONDUIT SYSTEM INSTALLED IN 1914, JOB NO. 2

Number of manholes	5
Conduit installed	3½-in. socket joint
Concrete mixture	1:5
Common labor	10-hr. day, 22.5 to 25 cts. per hour

MAN-HOURS

Item	Per cubic yard	Total hours	Per manhole
Labor excavating and placing sheeting	6.53	65	13
Labor setting and removing forms	....	26.5	5.3
Labor mixing and pouring concrete	8.9	125	25
Labor backfilling and hauling is included in trench work			
Total	....	216.5	43.3

LABOR COSTS

Item	Per cubic yard	Totals	Per manhole
Cost of excavating and placing sheeting	$1.47	$14.60	$ 2.92
Cost of setting and removing forms	.....	6.00	1.20
Cost of mixing and pouring concrete	2.00	33.15	6.63
Total	....	$53.75	$10.75

FIG. 87.—Typical recap sheets.

Material Costs

Item		Per cubic yard	Totals	Per manhole
Cost of cement (per bag)	0.0345	$ 0.74	$ 10.35	$ 2.07
Cost of sand, yards	0.0476	0.51	7.10	1.42
Cost of eyebolts		.....	1.95	0.39
Cost of frame and covers		.....	175.65	35.13
Cost of rails and reinforcing		.....	21.00	4.20
Total		.....	$216.05	$43.21

Totals

Item	Totals	Per manhole
Total labor cost	$ 53.75	$10.75
Total material cost	216.05	43.21
Total	269.80	$53.96

Miscellaneous Data

Item	Totals	Per manhole
Excavation, cubic yards	10	2
Material used, cement, bags	30	6
Material used, sand, yards	15	3
Approximate amount concrete used, cubic yards	14	2.8

Approximate cost of materials per cubic yard of concrete	$2.00
Approximate cost of labor per cubic yard of concrete	1.31
Total	$3.31

Fig. 88.—Typical recap sheets.

CONSTRUCTION DATA, JOB NO. 3

Four 4½-in. fiber conduit installed alongside an existing eight 4½-in. fiber duct. It was not possible to lay additional ducts on top of the existing ducts due to their depth, and make it possible to enter the manhole without interfering with existing cables.

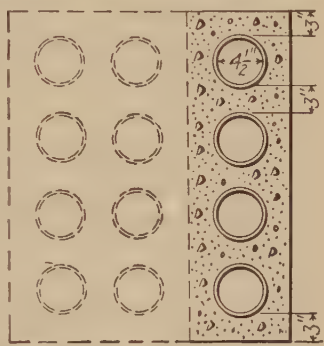


Fig. 89.—Four way duct fiber.

Removal of Pavement.—Brick pavement on 8-in. concrete base amounting to 151 sq. yd. This was removed by the hand method with bull points and sledge.

Excavating.—The soil was clay which was self-supporting.

Laying Conduit.—The conduit was laid by the built-up method using 3-in. square concrete separators. The joints were wrapped with cotton tape and painted with P & B compound No. 2 (see Fig. 89).

Concrete.—The concrete mixture was 1:3:6, portland cement, clean sharp sand, and ½-in. rock. Mixing was done in a ¼-yd. mixer, concrete being wheeled to trench for a distance of 50 to 100 ft.

Surplus Earth.—Hauled to a dump a distance of ¼ mile.

Hauling Material.—All material hauled by truck.

Analysis and Cost of Labor and Material of a Four-duct Underground Conduit, Four High, Alongside an Eight-duct Conduit, Job No. 3

Duct feet	2,040
Trench feet	510
Conduit installed	Four 4½-in. fiber-duct fiber socket joint
Concrete mixture	1:3:6 portland cement, sand, and chat
Concrete envelope	3-in. base, 3-in. sides and 3-in. separation
Common labor	9 hr. at 45 to 50 cts. per hour

Man-hours

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Labor removing pavement brick	1.066	161	0.316	0.0789
Labor excavating clay	6.275	1,073	2.104	0.5259
Labor laying conduit	.....	80	0.157	0.0392
Labor mixing and pouring concrete	7.053	536	1.051	0.2627
Labor backfilling	8.534	623	1.221	0.3053
Labor loading and hauling surplus dirt	4.296	421	0.825	0.2063
		263	0.516	0.1289
Total	.....	3,157	6.190	1.5472

Labor Costs

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Cost of removing pavement	$0.5298	$ 80.00	$0.157	$ 0.0392
Cost of excavation	3.045	520.70	1.021	0.2552
Cost of laying conduit	....	36.55	0.072	0.0179
Cost of mixing and pouring concrete	3.34	253.84	0.498	0.1244
Cost of backfilling	3.253	237.50	0.466	0.1164
Cost of loading and hauling surplus dirt	2.636	258.33	0.506	0.1266
Cost of hauling material	....	198.51	0.389	0.0973
Total	....	$1,585.43	$3.109	$0.7770

Miscellaneous Data

Item	Per yard	Totals	Per trench foot	Per duct foot
Paving removed, square yards	.....	151	0.296	0.0740
Excavating, cubic yards	.....	171	0.335	0.0838
Removing surplus dirt, cubic yards	.....	98	0.192	0.0480
Backfilling, cubic yards	.....	73	0.143	0.0358
Material used, cement, sack	.....	304	0.596	0.1490
Material used, sand, cubic yards	.....	34	0.067	0.0167
Material used, rock, cubic yards	.....	65	0.127	0.0319
Approximate amount of concrete used	.....	76	0.149	0.0372

Approximate cost of material per cubic yard	$ 7.172
Approximate cost of labor per cubic yard	3.34
Total	$10.512

CONSTRUCTION DATA, JOB NO. 4

Four 4½-in. fiber-duct, Harrington joint, installed in an unpaved street in solid rock.

Excavating.—In solid rock and shale which was removed by drilling with jack hammer and blasting.

Laying Conduit.—This conduit was laid by the built-up method using 3-in.-square concrete separation. The coupling joints

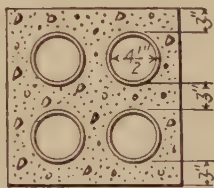


FIG. 90.—Four way duct fiber.

were painted with P & B compound No. 2 (see Fig. 90 for formation).

Concrete.—The concrete mixture was 1:3:6 of portland cement, clean sharp sand, and ½-in. rock. Mixing was done in a mixer, concrete being wheeled to the trench.

Surplus.—Rock hauled to a dump and backfilling done with earth. All hauling done with auto trucks.

Cost of Labor for Installing a Four-duct Underground Conduit, Job No. 4

Duct feet	940
Trench feet	256
Conduit used	4½-in. fiber duct
Concrete mixture	1:3:6 portland cement, sand, and chat
Concrete envelope	3-in. bottom, 3-in. top, 3-in. sides, and 3-in. separation

Man-hours

Item	Total hours	Per trench foot	Per duct foot
Excavating (rock and shale)	990	3.8672	1.0532
Laying conduit	30	0.1172	0.0319
Mixing and pouring concrete	94.5	0.3691	0.1005
Backfilling	84	0.3281	0.0893
Loading and removing surplus dirt	77.5	0.3027	0.0824
Hauling material	111	0.4336	0.1181
Total	1,387.0	5.4179	1.4754

Labor Costs

Item	Totals	Per trench foot	Per duct foot
Excavating (rock and shale)	$421.00	$1.6445	$0.4479
Laying conduit	14.85	0.0580	0.0158
Mixing and pouring concrete	43.20	0.1687	0.0459
Backfilling	35.90	0.1402	0.0382
Loading and removing surplus dirt	47.40	0.1852	0.0504
Hauling material	83.79	0.3273	0.0891
Total	$646.14	$2.5239	$0.6873

Average depth of trench: 4.5 ft. on four-way.

Miscellaneous Data

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Excavating, cubic yards	$6.79	62	0.2422	0.0660
Backfilling, cubic yards	0.92	39	0.1523	0.0415
Removing surplus dirt	2.10	23	0.0898	0.0245
Material used, cement, sacks	.....	60	0.2344	0.0638
Material used, rock, yards	.....	21	0.0820	0.0223
Material used, sand, yards	.....	8	0.0312	0.0085

Approximate amount of concrete, 15 cu. yd.	
Approximate cost of labor per cubic yard of concrete	$2.88
Approximate cost of material per cubic yard of concrete	6.86
Total cost	$9.74

CONSTRUCTION DATA, JOB NO. 5

Four 4-in. tile ducts, two wide, two high.

Removal of Pavement.—Brick paving on 9-in. concrete base was removed with a paving breaker operated by an air compressor.

Excavating.—After excavating for a depth of 1½ ft., a second layer of paving consisting of brick and concrete was encountered. The balance of the excavation was in rock which was removed by jack hammer, drilling, and blasting. The average depth of trench was 4.6 ft.

Laying Conduit.—The conduct was laid by the layer method using 4-in. square-tile duct with 1½-in. separation. All joints were wrapped with muslin 3 in. wide and painted with P & B compound No. 2 (see Fig. 91).

Concrete.—The concrete mixture was 1:3:6, of portland cement, clean sharp sand and ½-in. rock. Mixing done by a ¼-yd. mixer, concrete wheeled to trench.

Surplus.—Rock was hauled about 2 miles to dump, and earth from another trench near by was hauled to backfill rock trench which was back tamped with a pneumatic sand rammer.

Cost of Labor of Installing a Four-duct Underground Conduit, Job No. 5

Duct feet	1168
Trench feet	292
Conduit used	4-in. tile duct
Concrete mixture	1:3:6 portland cement, sand, and chat
Concrete envelope	3-in. top, 3-in. sides, 3-in. base, and 1½-in. separation
Common labor	9 hr. per day at 40 to 45 cts. per hour
Company trucks	9 hr. per day at 1.58 to 2.10 per hour

Man-hours

Item	Total hours	Per trench foot	Per duct foot
Removing paving	122.5	0.4195	0.1049
Excavating (rock and shale)	872.5	2.9880	0.7470
Laying conduit	66	0.2260	0.0565
Mixing and pouring concrete	142.5	0.4880	0.1220
Backfilling	58	0.1986	0.0497
Loading and removing surplus dirt	245	0.8390	0.2097
Hauling material	95.5	0.3271	0.0818
Total	1,602.0	5.4862	1.3716

Labor Costs

Item	Totals	Per trench foot	Per duct foot
Removing paving	$ 51.92	$0.1778	$0.0445
Excavating (rock and shale)	351.12	1.2025	0.3006
Laying conduit	28.55	0.0977	0.0244
Mixing and pouring concrete	59.37	0.2034	0.0509
Backfilling	25.79	0.0883	0.0221
Loading and removing surplus dirt	157.19	0.5383	0.1346
Hauling material	55.34	0.1895	0.0474
Total	$729.28	$2.4975	$0.6245

Miscellaneous Data

Item	Cost per cubic yard	Totals	Per trench foot	Per duct foot
Removing paving	$0.86	60.7	0.2080	0.0520
Excavating	7.17	49	0.1678	0.0419
Backfilling	0.92	28	0.0959	0.0240
Removing surplus dirt	3.83	41	0.1404	0.0351
Material used, cement	.....	78	0.2671	0.0668
Material used, rock	.....	18	0.0616	0.0154
Material used, sand	.....	9	0.0308	0.0077

Approximate amount of concrete used, 20 cu. yd.	
Approximate cost of labor per cubic yard of concrete	$2.97
Approximate cost of material per cubic yard of concrete	5.36
Total	$8.33

Cost of Man-hole, Job No. 5

Constructed in connection with a four-duct underground tile conduit

Manhole number	777
Standard manhole	8 ft. deep.
Concrete mixture	1:2:4 top; 1:3:5, walls.
Common labor	9 hr. per day at 40 to 45 cts. per hour

Labor	Man-hours	Costs
Excavating (rock)	301	$134.91
Setting forms	31	13.68
Mixing and pouring concrete	61	25.48
Setting casting	4	1.75
Backfilling	6	2.40
Removing forms	6	2.55
Hauling surplus dirt	79	47.55
Hauling material	40	29.93
Total	528	$258.25

Materials	Amount	Prices	Costs
Cement	47 sacks	$0.60	$ 28.20
Rock	8 yd.	2.20	17.60
Sand	4 yd.	2.30	9.20
Steel	210 lb.	3.50 per cwt.	7.35
30-in. cover and casting	....	....	34.48
Tools	....	....	3.73
Miscellaneous	....	....	5.75
Gas and oil	....	....	4.58
Tools repaired	....	....	10.50
Total	....	....	$121.39

Total cost of labor	$258.25
Total cost of material	121.39
	$379.64
Total cost of repaving	38.46
Total cost	$418.10

CONSTRUCTION DATA, JOB NO. 6

Analysis and cost of labor of a four-duct underground conduit installed in the parking between the sidewalk and curb.

Removal of Pavement.—The conduit being installed in the parking, paving was removed only at street crossings and some sidewalks.

Excavating.—The soil was clay and shale. All shale and hard clay digging was removed with pneumatic tools, the average depth being 4.9 ft., minimum 4.3 ft., maximum 8 ft. The maximum depth was caused by gas and water mains obstructing the trench.

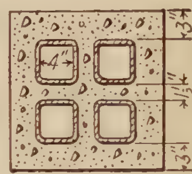


Fig. 91.—Four way duct tile.

Laying Conduit.—The conduit was laid by the layer method using 4-in., square-tile duct with 1½-in. separation. All joints were wrapped with muslin 3 in. wide and painted with P & B compound No. 2 (see Fig. 91).

Concrete.—The concrete mixture was 1:3:6 portland cement, clean sharp sand, and ½-in. rock. Concrete was wheeled to the trench, average wheel 100 ft.

Surplus.—Earth and dirt were hauled to a fill for building 2 miles distant. Backfilling was tamped with pneumatic rammers.

Hauling.—All material was hauled by auto trucks.

This work was done during the months of January and February. Temperature, 1 to 53°F.

COST OF LABOR OF INSTALLING A FOUR-DUCT UNDERGROUND CONDUIT, JOB NO. 6

Duct feet	6,282
Trench feet	1,570.5
Conduit used	4-in. tile duct single
Concrete mixture	1:3:6 portland cement, sand, and chat
Concrete envelope	3-in. top, 3-in. sides, 3-in. base, and 1½-in. separation
Common labor	9 hr. per day at 40 to 50 cts. per hour
Company's trucks	9 hr. per day at $1.58 to $2.10 per hour

MAN-HOURS

Item	Total hours	Per trench foot	Per duct foot
Removing paving	54	0.0344	0.0086
Excavating (clay)	2,396	1.5256	0.3814
Laying conduit	348	0.2216	0.0554
Mixing and pouring concrete	645	0.4107	0.1027
Backfilling	383	0.2439	0.0610
Loading and removing surplus dirt	550.5	0.3505	0.0876
Hauling material	335	0.2133	0.0533
Total	4,711.5	3.0000	0.7500

LABOR COSTS

Item	Totals	Per trench foot	Per duct foot
Removing paving	$ 21.85	$0.0139	$0.0035
Excavating (clay)	982.60	0.6256	0.1564
Laying conduit	148.95	0.0948	0.0237
Mixing and pouring concrete	267.54	0.1704	0.0426
Backfilling	159.24	0.1014	0.0254
Loading and removing surplus dirt	353.79	0.2253	0.0563
Hauling material	236.24	0.1504	0.0376
Total	$2,170.21	$1.3818	$0.3455

MISCELLANEOUS DATA

Item	Cost per cubic yard	Totals	Per trench foot	Per duct foot
Removing paving	$1.36	16	0.0102	0.0026
Excavating	2.42	405	0.2579	0.0645
Backfilling	0.65	245	0.1560	0.0390
Hauling surplus dirt	2.21	160	0.1019	0.0255
Material used, cement	.....	476	0.3031	0.0758
Material used, rock	.....	107	0.0681	0.0170
Material used, sand	.....	54	0.0344	0.0086

Approximate amount of concrete used, 126 cu. yd.	
Approximate cost of labor per cubic yard of concrete	$2.12
Approximate cost of material per cubic yard of concrete	5.12
Total cost	$7.24

Cost of Manholes, Job No. 6

Constructed in connection with a four-duct underground tile conduit line

Number of manholes	4
Standard manholes	From 8 to 10 ft. deep
Concrete mixture	1:2:4 top; 1:3:5 walls
Common labor	9 hr. per day at 40 to 45 cts. per hour

Man-hours—Labor

Item	Total hours	Per manhole
Removing paving	10	2.500
Excavating (clay)	484.5	121.125
Making sewer connections	191.5	47.875
Setting forms	125	31.250
Mixing and pouring concrete	249.5	62.375
Setting casting	17	4.250
Backfilling	21	5.250
Removing forms	44.5	11.125
Hauling surplus dirt	139	34.750
Hauling material	205	51.250
Total	1,487.0	371.750

Labor Costs

Item	Totals	Per manhole
Removing paving	$ 4.00	$ 1.000
Excavating (clay)	210.75	52.6875
Making sewer connections	78.54	19.6350
Setting forms	54.18	13.5450
Mixing and pouring concrete	105.71	26.4275
Setting casting	7.50	1.8750
Backfilling	8.45	2.1125
Removing forms	18.90	4.7250
Hauling surplus dirt	102.71	25.6775
Hauling material	154.35	38.5875
Total	$745.09	$186.2725

Miscellaneous Data

Item	Cost per cubic yard	Totals	Per manhole
Excavating, cubic yards	$2.22	95	23.750
Backfilling, cubic yards	0.77	11	2.750
Removing surplus dirt	1.87	55	13.750
Material used, cement, sacks	.....	183	45.750
Material used, rock, yards	.....	31.5	7.875
Material used, sand, yards	.....	16	4.000

Approximate amount of concrete used: 37 cu. yd.	
Approximate cost of labor per cubic yard of concrete	$2.86
Approximate cost of material per cubic yard of concrete	5.84
Total cost	$8.70

CONSTRUCTION DATA, JOB NO. 7

Analysis and cost of labor of a four-duct underground conduit consisting of 4,108 duct ft. and 1,027 trench ft. of 4-in. fiber-duct Harrington joint.

This conduit was installed during very cold weather. This section of conduit had to be built at once to give 13,200-volt service to a customer's substation which was not started until late fall.

Construction Data.—Paving was brick on 9-in. concrete base and in some places asphalt on 8-in. concrete base. Paving and concrete removed with sledge and bull points.

Excavating was in clay which was self-supporting with the exception of places where snow melting during midday caused the trench to be muddy at times. Average depth, 4 ft.

Laying Conduit.—Conduit was laid by the built-up method using 3-in. square concrete separators.

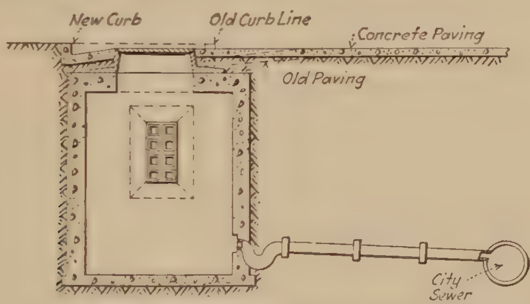


FIG. 92.—Manhole with sewer connection.

Concreting.—The concrete mixture was 1:3:6, portland cement, clean sharp sand, ½-in. rock. It was necessary to heat the sand for the concrete on all of this work due to the cold weather.

Backfilling.—Was done during the afternoon when the temperature was higher and in a great many cases it was necessary to build fires in the dirt piles in order to thaw them out to avoid backfilling with frozen earth which would cause settling of trench later.

Surplus earth was hauled to a dump about 2½ miles in auto dump trucks. Material was hauled to the job with the same trucks.

Manholes.—Built of concrete. Walls 8 in. thick. Floor of concrete 5 in. thick. Roof 8 in. of reinforced concrete. Mixture, 1:2:4 portland cement, sand, and ½-in. rock. General dimensions inside—5 ft. in depth, 5½ ft. in length (see Fig. 54). Two-way octagonal type manhole. All manholes drained to sewer (see Fig. 92).

ANALYSIS AND COST OF LABOR AND MATERIAL OF INSTALLING A FOUR-DUCT UNDERGROUND CONDUIT, JOB. NO. 7

Duct feet	4,108
Trench feet	1,027
Conduit used	4- to 4-in., fiber duct, Orangeburg
Concrete mixture	1:3:6 portland cement, sand, and chat
Concrete envelope	3-in. base, 3-in. sides, 3-in. top, and 3-in. separation
Common labor	9 hr. 45 to 50 cts. per hour

MAN-HOURS

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Removing paving, brick and asphalt	1.575	412	0.4011	0.1003
Excavating, clay	4.498	1111	1.0818	0.2705
Laying conduit	.....	123	0.1197	0.0299
Mixing and pouring concrete	3.847	227	0.2210	0.0533
Backfilling	1.356	217	0.2113	0.0528
Loading and removing surplus dirt	4.975	432.8	0.4214	0.1054
Hauling material	......	299	0.2911	0.0728
Total	.....	282.8	2.6974	0.6850

LABOR COSTS

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Removing paving	$0.7468	$ 195.36	$0.1902	$0.0476
Excavating	1.8904	466.95	0.4546	0.1137
Laying conduit	......	53.15	0.0517	0.0129
Mixing and pouring concrete	1.867	110.15	0.1027	0.0268
Backfilling	0.6328	101.26	0.0986	0.0247
Loading and removing surplus dirt	2.553	222.09	0.2162	0.0541
Hauling material	......	274.76	0.2675	0.0669
Total	......	$1,423.72	$1.3815	$0.3467

MISCELLANEOUS DATA

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Paving removed, square yards	0.74	261.6	0.2574	0.0644
Excavating, cubic yards	1.89	247	0.2405	0.0601
Backfilling, cubic yards	0.63	160	0.1558	0.0390
Removing surplus dirt, cubic yards	2.55	87	0.0847	0.0212
Material used, cement, sacks	....	225	0.2191	0.0547
Material used, rock, yards	....	49.5	0.0482	0.0121
Material used, sand	....	25	0.0243	0.0061

Approximate amount of concrete used, 59 cu. yd.

Approximate cost of labor per cubic yard of concrete	$1.87
Approximate cost of material per cubic yard of concrete	7.08
Total cost	$8.95

Cost of Manhole Constructed in Connection with a Four-duct Underground Conduit, Job No. 7

Number of manholes	4
Concrete mixture	1:2:4
Common labor	9 hr. at 45 to 50 cts. per hour

Man-hours

Item	Total hours	Per manhole
Removing paving, square yards	66	16.5
Excavating	123	30.75
Setting forms	110	27.5
Mixing and pouring concrete	175½	43.887
Removing forms	60½	15.125
Backfilling	36	9.000
Removing surplus dirt	44½	11.225
Hauling material	102½	25.625
Sewer connections	40	10.000

Labor Costs

Item	Totals	Per manhole
Removing paving	$ 31.15	$ 7.7875
Excavating	57.45	14.3625
Setting forms	46.35	11.5875
Mixing and pouring concrete	81.98	20.495
Removing forms	28.69	7.1725
Backfilling	16.65	4.1625
Removing surplus dirt	79.65	19.9125
Hauling material	62.48	15.626
Sewer connections	18.40	4.6000
Total	$422.80	$105.7000

Miscellaneous Data

Item	Totals	Per manhole
Paving removed, square yards	35	8.75
Excavation, cubic yards	81	20.25
Material used, cement, sacks	120	30
Material used, sand, cubic yards	13	4.25
Material used, rock, cubic yards	30	7.50
Backfilling	9	2.25
Surplus dirt removed	72	18
Approximate amount concrete used, square yards	40	10

Approximate cost material per cubic yard concrete	$ 8.13
Approximate cost labor per cubic yard concrete	2.05
Total cost	$10.18

JOB NO. 8

Analysis and cost of labor on an eight-duct underground conduit, constructed prior to the widening of street. The duct was laid back of the old curbing and in the space to be used for widening the street so that it was not necessary to remove paving except at the intersections of streets.

Construction Data.—Paving was asphalt on 8-in. concrete base.

Excavating was in clay which was of a good firm nature. Bracing was required at several points near the old trenches. The average depth of trench was 5½ ft. A large number of large trees had to be removed.

Laying Conduit.—Eight 3¼-in. square single-tile ducts laid by the layer method with 1-in. separation and 3 in. of concrete all around. Concrete mixed with a batch mixer, ¼-yd. capacity, one of portland cement, three of sand, and six of ¼- to ½-in. rock. Wood mandrel 3 ft. long and 3 in. square was used to get good alignment.

Backfilling.—All backfilling was hand tempered in 6-in. layers.

Surplus dirt was hauled to a dump with motor trucks at a distance of 1 to 3 miles, material being hauled on the same trucks on return trip.

Manholes.—Built of concrete, walls 8 in. thick, floor 5 in., roof 8 in. of reinforced concrete. Mixture was one of portland cement, two of sand, and four of ½-in. rock. General inside dimensions 6½ ft. in depth, 8½ ft. in length, and 5½ ft. in width (see Fig. 54, page 59, two-way octagonal-type manhole). All manholes were drained to the city sewer. The city sewer being at a higher level than the bottom of manholes, however, sewer traps were set in the walls above the floor of the manholes (see Fig. 92).

Analysis and Cost of Labor and Material of an Eight-duct Underground Conduit, Job No. 8

Duct feet	20,600
Trench feet	2,575
Conduit used	Eight 3¼-in. tile
Concrete mixture	1:3:6 portland cement, sand, and chat
Concrete envelope	3-in. base, 3-in. sides, 3-in. top and 1-in. separation
Common labor	9 hr. per day at 45 to 50 cts. per hour

Man-hours

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Removing paving	......	439.5	0.1706	0.0213
Excavating	......	2708	1.0866	0.1358
Laying conduit	......	912	0.3541	0.0442
Mixing and pouring concrete	......	996	0.3867	0.0483
Backfilling	......	1070	0.4155	0.0519
Loading and removing surplus dirt	......	635	0.2466	0.0308
Hauling material	......	775	0.3309	0.0376
Total	......	......	2.9910	0.3698

Labor Costs

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Removing paving	$1.1839	$ 51.60	$0.0200	$0.0025
Excavating	1.422	1272.50	0.4941	0.0617
Laying conduit	......	429.00	0.1666	0.0208
Mixing and pouring concrete	......	468.00	0.1817	0.0227
Backfilling	3.51	492.25	0.1911	0.0213
Loading and removing surplus dirt	0.53	396.50	0.1539	0.0192
Hauling material	......	351.58	0.1365	0.0170
Total	......	....	$1.3439	$0.1652

Miscellaneous Data

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Paving removed, square yards	1.1839	43.58	0.0169	0.0021
Excavating, cubic yards	1.42	895	0.3475	0.0434
Backfilling, cubic yards	3.51	140	0.0543	0.0068
Removing surplus dirt, cubic yards	0.53	750	0.2912	0.0364
Material used, cement, sacks	3.05	565	0.2193	0.0274
Material used, rock, cubic yards	1.62	300	0.1165	0.0146
Material used, sand, cubic yards	0.71	132	0.0512	0.0064

Approximate amount of concrete used, 185 cu. yd.

Approximate cost of labor per cubic yard	$5.57
Approximate cost of material per cubic yard	2.53
Total cost	$8.10

Cost of Manholes Constructed in Connection with an Eight-duct Conduit, Job No. 8

Number of manholes	6
Concrete mixture	1:2:4
Common labor	9 hr. at 45 to 50 cts. per hour

Man-hours—Labor

Item	Total hours	Per manhole
Removing paving per square yard	25.2	4.2
Excavating	509	84.833
Setting forms	332	55.333
Mixing and pouring concrete	302	50.333
Removing forms	87	14.5
Backfilling	42	7.00
Removing surplus dirt	223	37.133
Hauling material	108.5	18.083
Total	1,628.7	271.415

Labor Cost

Item	Totals	Per manhole
Removing paving	$ 11.42	$ 1.903
Excavating	217.40	36.566
Setting forms	128.38	21.396
Mixing and pouring concrete	146.65	24.441
Removing forms	41.44	6.906
Backfilling	18.45	3.075
Removing surplus dirt	143.90	23.966
Hauling material	63.03	10.505
Total	$770.67	$128.758

Miscellaneous Data

Item	Totals	Per manhole
Pavement removed, square yards	9.61	1.60
Excavation, cubic yards	148	24.67
Material used, cement, sacks	196	32.67
Material used, sand, cubic yards	23	3.83
Material used, rock, cubic yards	44	7.33
Backfilling	12	2
Surplus dirt removed	136	22.66
Approximate amount concrete used, square yards	49	8.16

Approximate cost material per cubic yard concrete	$4.953
Approximate cost labor per cubic yard concrete	2.62
Total cost	$7.573

CONSTRUCTION DATA, JOB NO. 9

Analysis and cost of labor of an eight-duct conduit consisting of four 4-in. and four 4½-in. fiber duct.

Removal of Pavement.—Paving consisted of 8-in. Wisconsin granite blocks grouted with portland cement on a 9-in. concrete base. This paving was exceptionally hard to remove. It was necessary to drill a hole in the block the full width of the trench to remove one row of blocks. The drilling was accomplished with a jack hammer. The removal of the block and concrete base was accomplished with a paving breaker operated by a portable air compressor.

Excavating.—The earth consisted of sandy loam and it was necessary to sheet and brace the entire trench. Many obstructions were encountered in the trench. There were four single street-car tracks and twenty-six single railroad tracks to go under; five separate duct lines, eight 15-in. catch-basin pipes to sewer; one 12-in. catch-basin pipe, one 16-in. water main, five 8-in., and sixteen 6-in. water pipes. This does not include a large number of small service pipes. The depth of the trench ranged from 7 to 9½ ft. deep (see Fig. 93).

Weather was very cold with much snow. Temperature ranged from zero to 50°. All concrete work was held up from January 4 to January 18, on account of extremely cold weather.

Bridging.—All railroad tracks were shored up with two 12- by 12-in. timbers under the ties and under each rail. The length of timbers was 16 ft.

Laying Conduit.—Conduit was laid by the built-up method 2 ft. wide and 4 ft. high using 3-in. square concrete separators.

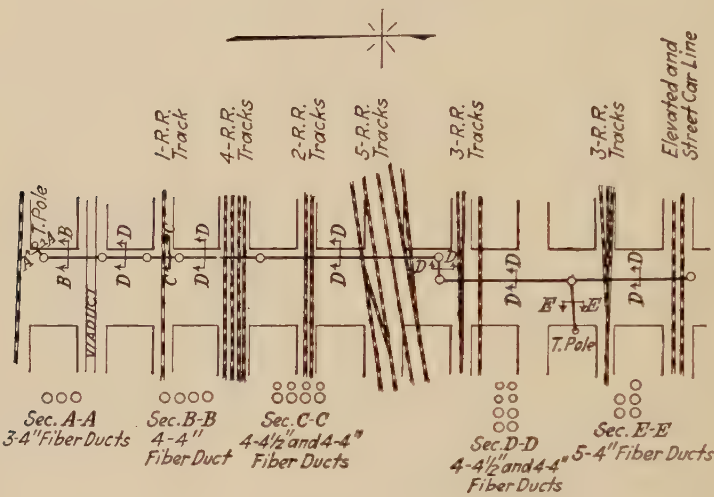
Concreting.—The concrete was poured directly into the trench where possible. At railroad crossings the concrete was wheeled in barrows over the railroad tracks for an average distance of 25 ft. The mixture was 1:3:6 portland cement, sand, ½-in. rock.

Backfilling.—Was done by hand and by sand rammers and was made difficult by the earth being frozen.

Hauling Surplus Dirt.—All surplus dirt was hauled by 5-ton motor trucks a distance of ¼ to ½ mile. Material was hauled by motor truck a distance of 2 to 3 miles.

Manholes.—Were built of concrete 9-in. walls, 5-in. floor, and 9-in. roof reinforced as shown in Fig. 54, page 59. Maximum

depth, 10 ft.; minimum depth, 8 ft.; average depth, 9 ft. 4 in. Portable wood forms were used. The mixture was 1:2:4 portland cement, sand, and ½-in. rock. General inside dimensions, 5½ ft. in width and 8½ ft. in length. All manholes were drained to the city sewer (see map of job No. 9).



Labor Cost of Manholes, Job No. 9

Constructed in connection with an eight-duct fiber conduit line in connection with job No. 9.
Number of manholes.............. 8
Concrete mixture................. 1:2:4 portland cement, sand, and chat
Common labor.................... 9 hr. per day at 40 to 45 cts. per hour

Man-hours

Item	Total hours	Man-hours per manhole
Removing paving	279	34,875
Sheeting and bracing	211	26,375
Excavating	1,679	209,875
Setting forms	345.5	43,188
Mixing and pouring concrete	514.5	64,312
Removing forms	103.5	12,938
Setting castings and backfilling	86	10,750
Making sewer connections	170	21,250
Loading and hauling surplus dirt	296	37,000
Hauling and handling material	375.5	46,938
Total	4,060.0	507,501

Labor Costs

Item	Totals	Cost per manhole
Removing paving	$ 115.93	$ 14.491
Sheeting and bracing	87.01	10.876
Excavating	622.16	77.770
Setting forms	145.11	18.139
Mixing and pouring concrete	208.87	26.109
Removing forms	41.60	5.200
Setting casting and backfilling	35.71	4.464
Making sewer connections	68.90	8.612
Loading and hauling surplus dirt	229.96	28.745
Hauling and handling material	258.40	32.300
Total	$1,813.65	$226.706

Jobs No. 10, 11, 12.—The work covered by Jobs No. 10, 11, and 12 consisted of constructing the greater part of a conduit system for accommodating transmission cables from the main generating station to four substations, and involved the installation of an eight-duct line 58,661 ft. long containing 469,288 ft. of 4½-in. socket-joint fiber conduit, and the construction of 177 manholes.

The specifications called for the construction of a system two ducts wide and four ducts high, with 3 in. of concrete surrounding the ducts on top, bottom, and sides, and 3 in. of concrete separating the horizontal and vertical tiers of ducts; the separation of the ducts at entrances to manholes was specified to be 18 in. between centers horizontally and 12 in. between centers vertically; the fanning of the ducts to be started 25 ft. back from the manhole entrance.

At the time the lines were built, the practice of separating the individual ducts, one from another, with 3 in. of concrete was rare. Various methods of laying the ducts to meet the specifications were considered, and it was at last decided to install the conduit by the built-up method of laying, which would allow pouring of the entire concrete envelope, exclusive of the base, around long sections of the built-up conduit at one time. The question of what type of vertical and horizontal separators to use was decided in favor of concrete separators, which were considered far better than wooden separators, because whatever type was used the separators would have to remain as part of the finished conduit line. The objections to the wooden separators were that if over 1 in. square they would very probably absorb moisture and swell, which would probably crack the concrete, and they would not offer sufficient resistance to fire in the event of a serious burn-out in the cables. The concrete separators first used were made with grooved spaces provided to fit the fiber conduit and hold the ducts in position. These grooved separators are shown in Fig. 43, page 51. During the progress of the installation it was found that a square-faced concrete separator answered every requirement and was less expensive to manufacture than the grooved separator, so it was adopted as standard. The square-faced separators are illustrated in Fig. 44*a*, page 52. Figure 28 shows a detailed plan for making the mold for these separators. Special separators were used where the ducts were fanned out to enter manholes. These special separators were

Fig. 93.—Fanned out ducts photographed out of trench to get a good view.

Fig. 94.—Fanned out duct construction in trench.

graded in size, and were placed 5 ft. apart in the conduit structure, starting 25 ft. back from the manhole entrance. The vertical and horizontal separation between ducts was thereby gradually increased from $8\frac{1}{8}$ in. to 18 in., between centers horizontally, and to 12 in. between centers vertically at the manhole entrances. Such a fanned-out line, set up on top of the

Fig. 95.—Conduit construction under railroad tracks.

ground, without the bottom layer of ducts, where it could be easily photographed, is shown in Fig. 93. A fanned-out line in the trench ready to receive its concrete envelope is shown in Fig. 94.

In laying the conduit, with concrete separators, a 3-in. base of concrete was placed, comparatively dry, on the bottom of the trench and tamped level in accordance with the grade stakes. Upon this base, the entire conduit structure was built up as

explained in "Laying Conduit—The Built-up Method," except that in addition to painting the mortise and tenon of the conduit joints with P & B compound, the joints were wrapped with 1½-in. cotton tape or webbing and a coat of compound was applied after wrapping.

The installation of the conduit lines in Jobs. No. 10, 11, and 12 involved a great deal of difficult construction.

The lines were installed through some of the older streets of the city, and many obstructions of various kinds were encountered.

Fig. 96.—Straight line manhole showing fanned out duct-entering manhole.

The minimum depth of the trench on these jobs was 5½ ft. and the maximum depth was 18 ft. The average depth was about 7 ft. for the 58,661 ft. of trench. The excavation was in all kinds of soil and rock, and was through clay; clay and loam; clay and loose rock; shale and limestone. Over a mile of the trench was through swampy soil where the trench rapidly filled with water. It was necessary to pump water out of the trench continuously until the work was completed on this section. Fiber conduit was laid in the bottom of the trench for use as a drain, so that the concrete base could be poured and the conduit structure built up and concreted in the usual manner. The conduit lines passed under railroad tracks at many points. At one place four tracks

crossed the street at an angle of 60 deg. (see Fig. 95). At this point there is a gas plant with large distributing mains coming out of the buildings. It was necessary to excavate the trench

FIG. 97.—"T" manhole concrete.

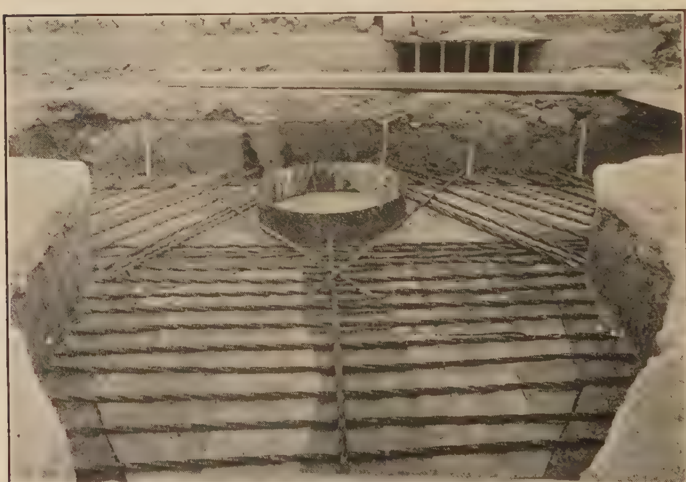


FIG. 98.—"T" manhole concrete top reinforcing.

at this point beneath these large pipes and also beneath large water mains. The bottom of the trench was 13 ft. below the ties of the railroad tracks. The tracks were supported by 12- by

12-in. yellow pine timbers 30 ft. long, two of which were placed under each rail. The trench had to be braced with planking and trench jacks. The distance under the tracks was 125 ft. Speed in construction was necessary as wet weather was due and

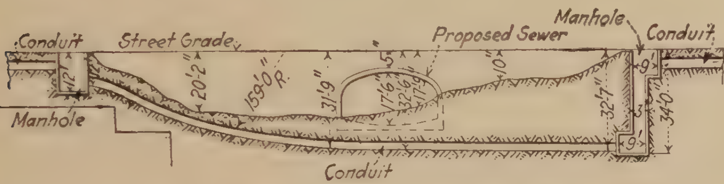


FIG. 99.—Elevation of conduit under creek.

the soil was of such a nature that a heavy rain would melt the clay into a fluid mud and cause the braces to drop in spite of good sheathing. Record time was made in this construction due to the speed with which fiber conduit can be laid by the built-up


FIG. 100.—Constructing conduit under creek.

method. This work could not have been completed in so short a time with short-length conduit of a heavy material.

At one place it was necessary to build the conduit line across a creek where the city planned to build, eventually, a 20- by 17-ft.

sewer on the creek bed. Not wishing to carry the power lines overhead for a period of from 2 to 5 years, it was decided to install the conduit beneath the bed of the creek. The installation was made during the winter, when the water in the creek was low. It was found necessary to build a dam in the creek to divert the water to one side until the line was constructed up to the dam. Then another dam was built to divert the water to the side of the creek under which the line had been completed and the conduit installation was continued under the creek bed. The bottom of the conduit line at the lowest point was about 12 ft. beneath the bed of the creek. A manhole, 12 ft. deep had been built in one bank of the creek, and another, 34 ft. deep, had been built in the other bank. The portion of the line installed under the creek as described above was built from the 12-ft. manhole in a downward curve across and beneath the bed of the creek, a distance of about 90 ft. with a drop of $30\frac{1}{2}$ ft.; the curve having a radius of 159 ft. This portion of the line was installed in a trench. From the 34-ft. manhole, the conduit was built in a tunnel, about 75 ft. long, which connected up with the conduit line built under the creek bed from the 12-ft. manhole. This construction was completed successfully, and cables were drawn into the ducts without the least trouble. Figure 99 is an elevation of the conduit across the creek. Figure 100 shows the construction at the creek.

During the progress of construction of the main conduit lines, many heavy rains fell, and each rain either caused trench cave-ins, or washed out the concrete and partially completed lines.

All concrete used on Jobs No. 10, 11, and 12 was mixed in rotary mixers. The concrete proportions for manholes and conduit envelopment below the high-water line were:

1 part portland cement.
2 parts sand.
4 parts broken stone less than $\frac{3}{4}$ in. ($\frac{1}{2}$-in. rock).

For concrete work above the high-water line the proportions were:

1 part portland cement.
3 parts sand.
6 parts broken stone less than $\frac{3}{4}$ in. ($\frac{1}{2}$-in. rock).

Under all railroad crossings the concrete covering of the conduit lines was increased from 3 in. to 9 in. in thickness, and the top of this concrete was maintained at a depth of at least 36 in. below the railroad ties.

After the completion of each section of conduit line a mandrel 30 in. long and $4\frac{1}{4}$ in. in diameter was pulled through each duct for proof of clearness and the duct ends at the manholes were plugged.

All conduit to terminal poles from manholes was $4\frac{1}{2}$-in. fiber conduit joined to $4\frac{1}{2}$-in. fiber bends of 90 deg. 36-in. radius, which were equipped with compromise couplings for $4\frac{1}{2}$-in. galvanized-iron pipe pole risers.

Manholes on Jobs No. 10, 11, 12.—All manholes were built of concrete with a 4-in. *P*-trap, a cast-iron strainer, and a clean-out for the sewer connection.

Sewer connections were made only where the floor was above the main sewer.

Manholes below the high-water line or where no city sewer existed had no sewer connections made.

Manholes below the high-water line were furnished with water-tight manhole covers and vent pipes. Two 3-in. fibre ducts were installed for vent pipes to the nearest pole. One pipe was run to the bottom of the manhole and one to a point near the roof. All bends used in connection with vent pipes were of a long radius.

Manholes above the high-water line were furnished with ventilated manhole covers.

A templet was made of 1-in. by 4-in. pine, having the shape and outside dimensions of the walls for the manholes. This templet was laid on the paving and marked around for cutting the pavement and excavating the manhole. When a manhole was excavated to the proper depth (a minimum of $8\frac{1}{2}$ ft.) the sewer connection was made, then 6 in. of concrete was poured for the floor; and when this concrete had set, portable wooden wall forms were set up on the floor of the manhole.

The end boards or duct entrances to the manholes had a flare which made a recess of 6 in., allowing more room for bending cables.

Eyebolts were set in line with the conduit for cable pulling. These eyebolts were made of 1-in. round mild steel with nut and 6-in. cut washer and were set in the forms before pouring the concrete.

The wall forms were allowed to remain in place for at least 48 hr., depending upon the temperature, after which they were removed and the roof forms were placed.

The concrete roof was reinforced with square, cold-twisted, ¾-in. steel bars on 6-in. centers.

The walls and roof of the manholes were 8 in. thick.

The straight-line manholes were 8½ ft. in length and 5½ ft. in width.

The *L*-corner manholes were 10½ ft. the long way, 8¼ ft. on the short part of the *L*, and 5½ ft. in width.

To construct a *T*-manhole another short part of the *L*-form was used on the opposite side.

Hauling Material and Surplus Dirt.—For convenience and economy, all material was stored at the underground storage yards which were centrally located in relation to Jobs No. 10, 11, and 12. Rock and sand were unloaded from the freight car into a hopper and unloaded from the hopper to 5-ton trucks and then hauled to the various construction jobs. On the return trips surplus dirt was hauled to a dump very close to the material-storage yard so that the trucks were loaded both ways.

Cement separators were also made at the storage yard which made it convenient for loading with a load of conduit.

Analysis and Cost of Labor of an Eight-duct, Underground, Transmission Conduit, Jobs No. 10, 11, and 12

Duct feet	469,288
Trench feet	58,658
Conduit installed	4½-in. socket-joint fiber conduit
Concrete mixture	1:3:6 and 1:2:4
Concrete envelope	3 in. all around—3 in. between ducts
Common labor	9-hr. day, 35 to 45 cts. per hour
Cost of manholes not included.	

Man-hours

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Removing paving	$2.75	40,588	0.6916	0.0864
Excavating	3.65	78,972	1.3463	0.1683
Mixing and pouring concrete	4.15	40,686	0.6936	0.0867
Laying conduit	....	15,735	0.2682	0.0335
Backfilling	2.42	28,089	0.4788	0.0598
Removing surplus dirt	....	15,980	0.2724	0.0341
Handling and hauling material	....	52,535	0.8955	0.1120
Total	....	272,585	4.6464	0.5808

Labor Costs

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Removing paving	$1.08	$ 15,813.00	$0.2696	$0.0337
Excavating	1.42	30,844.00	0.5258	0.0657
Mixing and pouring concrete	1.65	16,130.00	0.2749	0.0343
Laying conduit	....	6,456.00	0.1101	0.0137
Backfilling	0.92	10,610.00	0.1808	0.0226
Removing surplus dirt	0.65	6,552.00	0.1117	0.0140
Handling and hauling material	....	21,014.00	0.3582	0.0448
Total	....	$107,419.00	$1.8311	$0.2288
Cost of repaving by city	$5.25	$ 74,654.00	$1.2727	$0.1591

CONSTRUCTION DATA, JOB NO. 13

Weather.—Good. No interruptions.

Excavation.—This line of conduit was constructed in an unimproved street and it was necessary to go to extraordinary depths in some places to allow for a minimum of 30 in. between the top of the conduit structure and the grade line of the finished street. The soil was very hard and had to be picked the entire length and depth of the trench.

Laying Conduit.—The conduit was laid by the built-up method using 1-in. square wooden separators. The joints of the conduit were painted with P & B compound No. 2.

Concrete.—The concrete mixture was 1:7, portland cement and torpedo sand. Mixing was done in a ¼-yd. mixer and conveyed to the trench in wheelbarrows.

Surplus Earth.—Was loaded and hauled on wagons from one to three blocks for disposal.

Hauling Material.—Company work cars brought all material to a point within three blocks of the job where it was loaded on motor trucks and hauled to the work.

Analysis and Cost of Labor for Installing a Ten-duct Underground Conduit, Job No. 13

Duct feet	27,534.0 ft.
Trench feet	2,753.4 ft.
Conduit installed	3½-in. socket-joint fiber duct
Concrete mixture	1:7 portland cement and torpedo sand
Concrete envelope	3-in. all round 1-in. separation
Common labor	10 hr. 20 to 25 cts. per hour

Note.—This conduit was installed previous to street grading making it necessary to excavate to extra depth. No paving.

Man-hours

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Labor excavating clay	1.63	2,418	0.8782	0.0878
Labor laying conduit	.....	964	0.3501	0.0350
Labor mixing and pouring concrete	.....	1,855	0.6737	0.0674
Labor backfilling	0.963	1,045	0.3795	0.0379
Labor loading surplus dirt	1.20	436	0.1584	0.0158
Labor hauling material and surplus dirt (at $2.70 per hour)	.....	183	0.0665	0.0067
Total	.....	6,901	2.5064	0.2506

Labor Costs

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Cost of excavating	$0.367	$ 544.27	$0.1977	$0.0198
Cost of laying conduit	.....	212.45	0.0772	0.0077
Cost of mixing and pouring concrete	2.00	425.47	0.1545	0.0155
Cost of backfilling	0.211	235.28	0.0855	0.0085
Cost of loading surplus dirt	0.273	99.36	0.0360	0.0036
Cost of hauling material and surplus dirt	.....	497.27	0.1806	0.0181
Total		$2,014.10	$0.7315	$0.0732

Miscellaneous Data

Item	Totals	Per trench foot	Per duct foot
Excavation, cubic yards	1,484	0.5389	0.0539
Backfill, cubic yards	1,116	0.4053	0.0405
Surplus dirt removed, cubic yards	364	0.1322	0.0132
Approximate amount concrete used, cubic yards	213	0.0774	0.0077
Materials used, cement, bags	932	0.3385	0.0339
Materials used, sand, cubic yards	251	0.0912	0.0091
	4,360	1.5835	0.1583

Approximate cost material per cubic yard of concrete	$2.09
Approximate cost material per cubic yard of concrete	2.00
	$4.09

Average section length, 459 ft.

COST OF MANHOLES CONSTRUCTED IN CONNECTION WITH A TEN-DUCT CONDUIT, JOB NO. 13

Number of manholes	5
Conduit installed	3½-in. socket-joint fiber conduit
Concrete mixture	1:5 portland cement and torpedo sand
Common labor	10-hr. day, 20 to 25 cts. per hour

MAN-HOURS

Item	Per cubic yard	Total hours	Per man-hole
Labor excavation	2.19	186	37.2
Labor placing and removing forms	.....	160	32.0
Labor mixing and pouring concrete	15.67	235	47.0
Total	.....	581	116.2

LABOR COSTS

Item	Per cubic yards	Totals	Per manhole
Cost of excavation	$0.641	$ 54.50	$10.90
Cost of placing and removing forms	.....	36.10	7.22
Cost of mixing and pouring concrete	3.55	53.30	10.66
Total	.....	$143.90	$28.78

MISCELLANEOUS DATA

Item	Totals	Per manhole
Excavation, cubic yards	85	17
Material used, cement, bags	125	25
Material used, sand, cubic yards	17.5	3.5
Approximate amount of concrete used	15	3

Approximate cost materials per cubic yard of concrete	$3.29
Approximate cost labor per cubic yard of concrete	3.55
Total cost	$6.84

CONSTRUCTION DATA, JOB NO. 14

Weather.—Good. No interruptions.

Removal of Pavement.—The pavement was creosoted wooden blocks on an 8-in. concrete base. It was necessary to remove 741 sq. yd. which was done in 741 man-hr. or at the rate of 1 man-hr. per square yard.

Excavation.—This line was installed under a sidewalk which was constructed of 24-in. square cement slabs, 2 in. thick, set on a sand base. One row of these slabs adjoining the parkway was removed. The parkway was 4 ft. wide, located between the sidewalk and the curb. Many of the slabs were broken and replaced with new ones. The cost of removing, replacing, and renewing slabs was charged to excavation.

The soil in which the trench was dug was clay and sand and supported itself without bracing.

Laying Conduit.—The conduit was laid by the built-up method, using 1-in. square wooden separators. The joints of the conduit were painted with P & B compound No. 2.

Concrete.—The concrete mixture was 1:7, portland cement and torpedo sand. Mixing was done in a ¼-yd. mixer and conveyed to the trench in wheelbarrows. The average haul of concrete with wheelbarrow was 50 ft.

Surplus Earth.—Was loaded on motor trucks and wagons and hauled five blocks for disposal.

Hauling Material.—Company work cars and trucks hauled all materials to the job. The average haul was 3 miles.

Analysis and Cost of Labor for Installing a Ten-duct Underground Conduit, Job No. 14

Duct feet	36,353.0 ft.
Trench feet	3,635.3 ft.
Conduit installed	3½-in. socket-joint fiber conduit
Concrete mixture	1:7 portland cement and sand
Concrete envelope	3 in. all around 1-in. separation
Common labor	10 hr. 20 to 25 cts. per hour

Man-hours

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Labor removing paving square yard cement sidewalk, tile 2-ft. square intersection creosoted block	.....	Included in excavation		
Labor excavating (clay and sand)	1.69	3.193	0.8783	0.0878
Labor laying conduit	.....	0.848	0.2333	0.0233
Labor mixing and pouring concrete	.....	1.708	0.4698	0.0470
Labor backfilling	.505	0.745	0.2050	0.0205
Labor loading surplus dirt	1.29	0.535	0.1472	0.0147
Labor hauling material and surplus dirt at 2.70 per hour	.....	0.156	0.0429	0.0043
Total	.....	7.185	1.9767	0.1976

Labor Costs

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Cost of removing pavement	.....	Included in excavation		
Cost of excavating	$0.38	$ 718.45	$0.1976	$0.0198
Cost of laying conduit	.....	191.00	0.0525	0.0053
Cost of mixing and pouring concrete	.....	384.52	0.1058	0.0106
Cost of backfilling	0.114	167.67	0.0461	0.0046
Cost of loading surplus dirt	0.273	113.29	0.0312	0.0031
Cost of hauling material and surplus dirt	.....	422.68	0.1163	0.0116
Total	.....	$1,997.61	$0.5495	$0.0550

Miscellaneous Data

Item	Totals	Per trench foot	Per duct foot
Pavement removed, square yards	741	0.2038	0.0204
Excavation, cubic yards	1,892	0.5204	0.0520
Backfill	1,474	0.4055	0.0405
Surplus dirt removed, cubic yards	415	0.1142	0.0114
Approximate amount concrete used, cubic yards	269	0.0740	0.0074
Pavement replaced, square yards	741	0.2038	0.0204
Material used, cement, bags	1,236	0.3400	0.0340
Material used, sand, cubic yards	333	0.0916	0.0092
	7,101	1.9533	0.1953

Approximate cost material per cubic yard of concrete	$2.20
Approximate cost labor per cubic yard of concrete	1.43
Total cost	$3.63

Average section length, 404 ft.

COST OF MANHOLES CONSTRUCTED IN CONNECTION WITH A TEN-DUCT CONDUIT, JOB NO. 14

Number of manholes	9
Conduit installed	3½-in. socket-joint fiber conduit
Concrete mixture	1:5 portland cement and torpedo sand
Common labor	10-hr. per day, 20 to 25 cts. per hour

MAN-HOURS

Item	Per cubic yard	Total hours	Per man-hole
Labor excavating	2.6	351	39
Labor placing and removing forms	.....	288	32
Labor mixing and pouring concrete	15.70	424	47
Total	.....	1,063	118

LABOR COSTS

Item	Per cubic yard	Totals	Per man-hole
Cost of excavation	$0.591	$ 79.84	$ 8.87
Cost of placing and removing forms	.....	65.98	7.33
Cost of mixing and pouring concrete	3.48	93.96	10.44
Total	.....	$239.78	$26.64

MISCELLANEOUS DATA

Item	Total	Per manhole
Excavation, cubic yards	135	15
Material used, cement, bags	216	24
Material used, sand, cubic yards	31.5	3.5
Approximate amount of concrete used, cubic yards	27	3

Approximate amount of material per cubic yard of concrete	$3.23
Approximate amount of labor per cubic yard of concrete	3.48
Total cost	$6.71

CONSTRUCTION DATA, JOB NO. 15

Weather.—Bad. Numerous interruptions.

Excavation.—This line of conduit was laid in the parkway between the curb and sidewalk alongside of an old clay duct line carrying 13,200-volt cables. A shallow trench was excavated, a minimum of 20 in. between the top of the duct structure and the ground level being maintained. The soil was clay and loam, and easy to dig, although the trench had to be braced at a number of points in order to keep the old clay duct line in alignment. It rained for several days which damaged the trench in several places and slightly increased the excavation costs. The removal of pavement at street intersections is included in excavation.

Laying Conduit.—The conduit was laid by the built-up method, using 1-in. square wooden separators. The joints of the conduit were painted with P & B compound No. 2. Good speed was made in laying the conduit on account of the shallow trench.

Concrete.—The concrete mixture was 1:7, portland cement and torpedo sand. Mixing was done in a ¼-yd. mixer.

Backfilling.—After the trench was backfilled all sod was replaced over the trench, the cost of this being charged to backfilling.

Surplus Earth.—Was hauled away by wagons and trucks a distance of about five blocks.

Hauling Material.—Company work cars hauled all material directly to the job, an average of about 2 miles.

Analysis and Cost of Labor for Installing a Ten-duct Underground Conduit, Job No. 15

Duct feet	46,460.0
Trench feet	4,646.0
Conduit installed	3½-in. socket-joint fiber conduit.
Concrete mixture	1:7 portland cement and torpedo sand.
Concrete envelope	3 in. all around 1-in. separation.
Common labor	10 hr. 20 to 25 cts. per hour.

Man-hours

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Labor excavating (sand, clay, loam)	0.952	2,098	0.4516	0.0452
Labor laying conduit	.....	922	0.1984	0.0198
Labor mixing and pouring concrete	.....	1,815	0.3906	0.0391
Labor backfilling	0.349	583	0.1255	0.0125
Labor loading surplus dirt	0.21	649	0.1397	0.0140
Labor hauling material and surplus dirt	.....	167	0.0359	0.0036
Total	.....	6,234	1.3417	0.1342

Labor Costs

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Cost of excavating	$0.214	$ 472.10	$0.1016	$0.0102
Cost of laying conduit	.....	203.00	0.0437	0.0044
Cost of mixing and pouring concrete	.....	408.58	0.0879	0.0088
Cost of backfilling	0.079	131.26	0.0282	0.0028
Cost of loading surplus dirt	0.273	146.05	0.0314	0.0031
Cost of hauling material and surplus dirt (2.70 per hour)	.....	451.32	0.0971	0.0097
Total	.....	$1,812.31	$0.3899	$0.0390

Miscellaneous Data

Item	Totals	Per trench foot	Per duct foot
Pavement removed, square yards	None		
Excavation, cubic yards	2,204	0.4743	0.0474
Backfill	1,669	0.3592	0.0359
Surplus dirt removed, cubic yards	535	0.1151	0.0115
Approximate amount concrete used, cubic yards	344	0.0740	0.0074
Pavement replaced, square yards	40	0.294	0.0294
Material used, cement, bags	None		
Material used, sand, cubic yards	426	0.0917	0.0092
Total	5,218	1.2294	0.1229

Approximate cost of material per cubic yard of concrete	$2.20
Approximate cost of labor per cubic yard of concrete	1.19
Total cost	$3.39

Average section length, 450 ft.

Cost of Manhole Constructed in Connection with a Ten-duct Conduit, Job No. 15

Number of manholes	10
Conduit installed	3½-in. socket-joint fiber conduit.
Concrete mixture	1:5 portland cement and torpedo sand.
Common labor	10-hr. day, 20 to 25 cts. per hour.

Man-hours

Item	Per cubic yard	Total hours	Per man-hole
Labor excavating, tearing out old manholes	13.27	929	92.9
Labor placing and removing forms	.....	320	32
Labor mixing and pouring concrete	13.43	470	47
Total	.....	1719	171.9

Labor Costs

Item	Per cubic yard	Totals	Per man-hole
Cost of excavation, tearing out old manholes	$2.98	$208.47	$20.85
Cost of placing and removing forms	.....	80.00	8.00
Cost of mixing and pouring concrete	3.05	106.60	10.66
Total	.....	$395.07	$39.51

Miscellaneous Data

Item	Totals	Per manhole
Excavation, cubic yards	70	$ 7
Material used, cement, bags	240	24
Material used, sand, cubic yards	40	4
Approximate amount of concrete used, cubic yards	35	3.5

Approximate cost of material per cubic yard of concrete	$2.81
Approximate cost of labor per cubic yard of concrete	3.05
Total cost	$5.86

CONSTRUCTION DATA, JOB NO. 16

Weather.—Good. No interruptions.

Removal of Pavement.—In this job it was necessary to remove 657 sq. yd. of macadam pavement which was 12 in. thick. The removal of pavement required 788 man-hr., or an average of 1⅕ man-hr. per square yard.

Excavation.—This line of conduit was installed in the street 4 ft. from the curb. The soil was self-supporting clay. The trench was excavated to a depth that assured a minimum of 30 in. between the top of the duct structure and the street level.

Laying Conduit.—The conduit was laid by the built-up method, using 1-in. square wooden separators. The joints of the conduit were painted with P & B compound No. 2. Very good time was made in laying, as the trench was clear and free from bracing.

Concrete.—The concrete mixture was 1:7, portland cement and torpedo sand. Mixing was done in a ¼-yd. mixer. The maximum wheelbarrow haul in concreting was about 100 ft.

Surplus Earth.—Was loaded and hauled in wagons and trucks an average of about six to seven blocks.

Hauling Material.—Company work cars and trucks were used for hauling all material to the job a distance that averaged about 1 mile.

Analysis and Cost of Labor for Installing a Ten-duct Underground Conduit, Job No. 16

Duct feet	29,581.0
Trench feet	2,958.1
Conduit installed	3½-in. socket-joint fiber duct
Concrete mixture	1:7 portland cement and torpedo sand
Concrete envelope	3-in. all around 1-in. separation
Common labor	10 hr., 20 to 25 cts. per hour

Man-hours

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Labor removing paving, square yards, macadam 12 in. deep	.....	788	0.2664	0.0266
Labor excavating, clay	1.02	1,304	0.4408	0.0441
Labor laying conduit	.....	558	0.1886	0.0189
Labor mixing and pouring concrete	.....	1,102	0.3725	0.0373
Labor backfilling	0.447	535	0.1809	0.0181
Labor loading surplus dirt	1.21	421	0.1423	0.0142
Labor hauling material and surplus dirt	.....	123	0.0416	0.0042
Total	.....	4,831	1.6331	0.1634

Labor Costs

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Cost of removing paving	.....	$ 177.48	$0.0600	$0.0060
Cost of excavating	$0.229	293.41	0.0992	0.0099
Cost of laying conduit	.....	125.61	0.0425	0.0042
Cost of mixing and pouring concrete	.....	248.00	0.0838	0.0084
Cost of backfilling	0.101	120.70	0.0408	0.0041
Cost of loading surplus dirt	0.273	94.73	0.0320	0.0032
Cost of hauling material and surplus dirt	.....	350.85	0.1186	0.0119
Total	.....	$1,410.78	$0.4769	$0.0477

Miscellaneous Data

Item	Totals	Per trench foot	Per duct foot
Pavement removed, square yards	657	0.2221	0.0222
Excavation, cubic yards	1,281	0.4330	0.0433
Backfill	1,196	0.4043	0.0404
Surplus dirt removed, cubic yards	347	0.1173	0.0117
Approximate amount concrete used, cubic yards	219	0.0740	0.0074
Pavement replaced, square yards	657	0.2221	0.0222
Material used, cement, bags	1,004	0.3394	0.0339
Material used, sand, cubic yards	271	0.0916	0.0092
Total	5,632	1.9038	0.1903

Approximate cost material per cubic yard of concrete	$2.20
Approximate cost labor per cubic yard of concrete	1.13
Total cost	$3.33

Average section length 492 ft.

Cost of Manholes Constructed in Connection with a Ten-duct Conduit, Job No. 16

Number of manholes	5
Conduit installed	3½-in. socket-joint fiber conduit
Concrete mixture	1:5 portland cement and torpedo sand
Common labor	10 hr. per day, 20 to 25 cts. per hour

Man-hours

Item	Per cubic yard	Total hours	Per manhole
Labor excavation	2.19	186	37.2
Labor placing and removing forms	.....	160	32.0
Labor mixing and pouring concrete	15.67	235	47.0
Total	.....	581	116.2

Labor Costs

Item	Per cubic yard	Totals	Per manhole
Cost of excavation	$6.41	$ 54.50	$10.90
Cost of placing and removing forms	.....	36.10	7.22
Cost of mixing and pouring concrete	3.55	53.30	10.66
Total	.....	$143.90	$28.78

Miscellaneous Data

Item	Totals	Per manhole
Excavation cubic yards	85	17
Material used, cement, bags	125	25
Material used, sand, cubic yards	17.5	3.5
Approximate amount of concrete used	15	3

Approximate cost materials, cubic yard of concrete	$3.29
Approximate cost labor, cubic yard of concrete	3.55
Total	$6.84

CONSTRUCTION DATA, JOB NO. 17

Weather.—Good, fair, and rainy.

Excavation.—This line of conduit was installed in streets where there was very little grading and no pavement. The soil consisted mostly of clay and loose sand, and in some places loose sand and boulders. The entire line of trench had to be sheathed on both sides. The conduit line passed under one main-line railroad track and under three street-railway crossings. Portions of the trench were excavated 10 ft. deep, and part of the conduit line was built on top of the ground and a fill made over it. In all portions of the line a minimum of 30 in. from the top of the conduit structure to the established final street grade was maintained. In trenching under the railroad tracks it was necessary to lay two heavy timbers 20 ft. long under the ties and directly under each rail to support trains passing over the trench at this point.

Sheeting.—A total of 26,032 ft. of trench had to be sheeted, using 1½-in. by 10-in. by 8-ft. planking. For sheeting the trench a total of 5,495 man-hr. was required, or an average of 0.2111 man-hr. per foot of sheeting. Under the railroad tracks sheeting had to be driven in two sets of 4 ft. each. This had to be done quickly between trains.

Laying Conduit.—The conduit was laid by the built-up method, using 1-in. square wooden separators. The joints of the conduit were painted with P & B compound No. 2. The laying of the conduit was very slow, due to the many braces in the trench.

Concrete.—The concrete mixture was 1:7, portland cement and torpedo sand. Mixing was done in ¼-yd. mixers. At several points it was possible to use sand and gravel out of the trench for concrete, which cut slightly the cost of hauling surplus earth.

Surplus Earth.—Was hauled to low parts of the street to be used for fill.

Hauling Material.—All material was hauled by work car from 2 to 4 miles, and transferred to trucks or wagons for a haul from one to six blocks.

Miscellaneous.—Rain caused some delay, mostly from the lack of sewers, but the subsoil being sand, the excess water soon drained into the ground.

ANALYSIS AND COST OF LABOR FOR INSTALLING TEN-DUCT UNDERGROUND CONDUIT, JOB NO. 17

Duct feet	130,169.0
Trench feet	13,524.0
Conduit used	3½-in. socket-joint fiber conduit
Concrete mixture	1:7 portland cement and torpedo sand
Concrete envelope	3 in. all around, 1-in. separation
Common labor	10 hr., 20 to 25 cts. per hour

MAN-HOURS

Item	Per cubic yards	Total hours	Per trench foot	Per duct foot
Labor excavating sand and clay	0.853	5,783	0.4276	0.0444
Labor laying conduit	.....	4,188	0.3097	0.0322
Labor mixing and pouring concrete	.....	7,555	0.5586	0.0580
Labor backfilling	1.144	6,042	0.4467	0.0464
Labor loading surplus dirt	1.212	1,818	0.1344	0.0140
Labor hauling material and surplus dirt	.....	850	0.0628	0.0065
Labor placing sheathing	.....	5,495	0.4063	0.0422
Total	.....	31,731	2.3461	0.2437

LABOR COSTS

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Cost of excavating	$0.192	$1,301.23	$0.0962	$0.0100
Cost of laying conduit	.....	942.37	0.0697	0.0072
Cost of mixing and pouring concrete	.....	1,700.00	0.1257	0.0131
Cost of backfilling	0.257	1,359.05	0.1005	0.0105
Cost of loading surplus dirt	0.273	409.22	0.0303	0.0031
Cost of hauling material and surplus dirt	.....	2,297.45	0.1699	0.0176
Cost of placing sheathing	.....	1,236.52	0.0914	0.0095
Total	.....	$9,245.84	$0.6837	$0.0710

MISCELLANEOUS DATA

Item	Totals	Per trench foot	Per duct foot
Pavement removed, square yards			
Excavation, cubic yards	6,778	0.5012	0.0521
Backfill, cubic yards	5,279	0.3903	0.0406
Surplus dirt removed, cubic yards	1,499	0.1108	0.0115
Approximate amount concrete used, cubic yards	964	0.0713	0.0074
Material used, cement, bags	4,432	0.3277	0.0340
Material used, sand, cubic yards	1,195	0.0884	0.0092
Placing sheathing, trench feet	13,016	0.9624	0.1000
Total	33,163	2.4521	0.2548

Approximate cost material per cubic yard of concrete	$2.21
Approximate cost labor per cubic yard of concrete	1.76
Total	$3.97

Average section length, 500 ft.

Cost of Manhole Constructed in Connection with a Ten-duct Conduit, Job No. 17

Number of manholes	28
Conduit installed	3½-in. socket-joint fiber conduit
Concrete mixture	1:5 portland cement and torpedo sand
Common labor	10-hr. day, 20 to 25 cts. per hour

Man-hours

Item	Per cubic yard	Totals	Per man-hole
Labor excavation	2.6	1,092	39
Labor placing and removing forms	.....	896	32
Labor mixing and pouring concrete	15.19	1,276	45.57
Total	.....	3,264	116.57

Labor Costs

Item	Per cubic yard	Total	Per man-hole
Cost of excavation	$0.591	$248.36	$ 8.87
Cost of placing and removing forms	.....	202.16	7.22
Cost of mixing and pouring concrete	3.55	298.48	10.66
Total	.....	$749.00	$26.75

Miscellaneous Data

Item	Totals	Per manhole
Excavation, cubic yards	420	15
Material used, cement, bags	672	24
Material used, sand, cubic yards	98	3.5
Approximate amount of concrete used, cubic yards	84	5

Approximate cost of material per cubic yard of concrete	$3.23
Approximate cost of labor per cubic yard of concrete	3.55
Total	$6.78

CONSTRUCTION DATA, JOB NO. 18

Excavation.—The soil in which this line of conduit was installed was clay and rock mixed, some of the rock being solid limestone. The trench paralleled a gas main, and being an old main it was considered dangerous to use dynamite in excavating the trench. The rock was removed by the plug-and-feather method. The plug-and-feather method is slow, but was by far the safest considering the conditions encountered. A minimum distance of 30 in. was maintained between the top of the conduit structure and the street level.

Laying Conduit.—The conduit was laid by the built-up method, using 1-in. square wooden separators. The joints of the conduit were painted with P & B compound No. 2.

Concrete.—The concrete mixture was 1:7, portland cement and torpedo sand. Mixing was done in $\frac{1}{4}$-yd. mixers.

Surplus Earth.—Was removed by work cars, trucks, and wagons.

Hauling Material.—All material was hauled by work cars, trucks, and wagons.

ANALYSIS AND COST OF LABOR FOR INSTALLING A TEN-DUCT UNDERGROUND CONDUIT, JOB NO. 18

Duct feet	115,240
Trench feet	11,524
Conduit used	3½-in. socket-joint fiber duct
Concrete mixture	1:7 portland cement and torpedo sand
Concrete envelope	3 in. all around 1-in. separation
Common labor	10 hr., 20 to 25 cts. per hour

MAN-HOURS

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Labor excavating sand and clay	1.087	6,522	0.5659	0.0566
Labor laying conduit	.....	2,967	0.2574	0.0257
Labor mixing and pouring concrete	.....	5,335	0.4629	0.0463
Labor backfilling	0.582	2,719	0.2359	0.0236
Labor loading surplus dirt	1.213	1,610	0.1397	0.0140
Labor hauling material and surplus dirt	.....	665	0.0577	0.0058
Labor placing sheathing	.....	5,121	0.4443	0.0444
Total	.....	24,939	2.1638	0.2164

LABOR COSTS

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Cost of excavating	$0.245	$1,468.50	$0.1274	$0.0127
Cost of laying conduit	.....	667.71	0.0579	0.0058
Cost of mixing and pouring concrete	.....	1,200.42	0.1042	0.0104
Cost of backfilling	0.131	612.97	0.0532	0.0053
Cost of loading surplus dirt	0.273	366.27	0.0314	0.0031
Cost of hauling material and surplus dirt	.....	1,807.58	0.1568	0.0157
Cost of placing sheathing	.....	1,156.40	0.1000	0.0100
Total	.....	$7,271.85	$0.6309	$0.0630

MISCELLANEOUS DATA

Item	Totals	Per trench foot	Per duct foot
Excavating, cubic yards	6,000	0.5206	0.0521
Backfill, cubic yards	4,673	0.4055	0.0406
Surplus dirt removed, cubic yards	1,327	0.1151	0.0115
Approximate amount concrete used, cubic yards	853	0.0740	0.0074
Material used cement, bags	3,920	0.3401	0.0340
Material used sand, cubic yards	1,057	0.0917	0.0092
Placing sheating, trench-feet	11,524	0.9999	0.1000
	29,354	2.5469	0.2548

Approximate cost material per cubic yard of concrete	$2.21
Approximate cost labor per cubic yard of concrete	1.41
Total	$3.62

Cost of Manhole Constructed in Connection with a Ten-duct Underground Conduit, Job No. 18

Number of manholes	25
Conduit installed	3½-in. socket-joint fiber conduit
Concrete mixture	1:5 portland cement and torpedo sand
Common labor	10 hr. per day, 20 to 25 cts. per hour

Man-hours

Item	Per cubic yard	Total hours	Per man-hole
Labor excavation	2.6	975	39
Labor placing and removing forms	.....	800	32
Labor mixing and pouring concrete	15.67	1,175	47
Total	.....	2,950	118

Labor Costs

Item	Per yard	Total	Per manhole
Cost of excavation	$0.591	$221.75	$ 8.87
Cost of placing and removing forms	.....	180.50	7.22
Cost of mixing and pouring concrete	3.55	266.50	10.66
Total	.....	$688.75	$26.75

Miscellaneous Data

Item	Totals	Per manhole
Excavation, cubic yards	375	15
Material used, cement, bags	600	24
Material used, sand, cubic yards	87.5	3.5
Approximate amount of concrete used, cubic yards	75	3
Approximate cost of material per cubic yard of concrete	$3.25	
Approximate cost of labor per cubic yard of concrete	3.55	
Total	$6.78	45.5

CONSTRUCTION DATA, JOB NO. 18

Weather.—Good. No interruptions.

Labor.—Ten-hour day.

Removal of Pavement.—In constructing this line of conduit it was necessary to remove 266 sq. yd. of pavement consisting of asphalt on a concrete base. The removal of pavement required 544 man-hr., or an average of 2.04 man-hr. per square yard.

CONSTRUCTION DATA, JOB NO. 19

Weather.—Good. No interruptions.

Removal of Pavement.—Consists of asphalt on an 8-in. concrete base.

Excavation.—The soil in which this conduit was installed was clay with some fill. Some bracing was necessary. Several small water services were renewed due to old pipe and leakages. This conduit passed under two street railway tracks.

Laying Conduit.—The conduit was laid by the built-up method using 3-in. square concrete separators. The joints of the conduit were painted with P & B paint.

Concrete.—The concrete was mixed in a $\frac{1}{4}$-yd. mixer and was wheeled from the mixer to the trench for a distance not over 100 ft.

Hauling Material and Surplus Dirt.—All hauling was done with 5-ton trucks for a distance of 3 miles. A load of material was hauled to the job and a load of surplus dirt hauled on the return trip.

ANALYSIS AND COST OF LABOR FOR INSTALLING A TEN-DUCT UNDERGROUND CONDUIT, JOB NO. 19

Duct feet	11,550
Trench feet	1,155
Conduit used	Four 4½-in. and six 4-in. fiber Orangeburg
Concrete mixture	1:3:6 portland cement, sand, and chat
Concrete envelope	3-in. base, 3-in. sides, 3-in. top and 3-in. separation
Common labor	9 hr. at 45 to 50 cts. per hour

MAN-HOURS

Item	Total hours	Per trench foot	Per duct foot
Removing paving	304.5	0.2632	0.0263
Excavating	1,991	1.7238	0.1723
Laying conduit	332	0.2874	0.0287
Mixing and pouring concrete	603	0.5307	0.0530
Backfilling	332.5	0.2874	0.0287
Loading and removing surplus dirt	878	0.7602	0.0760
Hauling material	344.5	0.2987	0.0298

LABOR COSTS

Item	Totals	Per trench foot	Per duct foot
Removing paving	$ 139.54	$0.1208	$0.0120
Excavating	878.34	0.7604	0.0760
Laying conduit	153.47	0.1328	0.0132
Mixing and pouring concrete	322.75	0.2794	0.0279
Backfilling	152.84	0.1320	0.0132
Loading and removing surplus dirt	725.09	0.6278	0.0627
Hauling material	234.47	0.2030	0.0203
Total	$2,606.20		

MISCELLANEOUS DATA

Item	Per cubic yard	Total	Per trench foot	Per duct foot
Paving removed, square yards	0.88	158	0.1368	0.0137
Excavating, cubic yards	1.79	488.7	0.4231	0.0423
Backfilling, cubic yards	0.55	277.7	0.2400	0.0240
Removing surplus dirt	3.43	211	0.1826	0.0183
Material used, cement, sacks	....	506	0.4381	0.0438
Material used, rock, yards	....	141	0.1220	0.0122
Material used, sand, yards	....	69	0.0597	0.0060

Approximate amount of concrete used, 144 cu. yd.

Cost of labor, per cubic yard	$1.97
Cost of material per cubic yard	6.64
Total cost	$8.61

CONSTRUCTION DATA, JOB NO. 20

Weather.—Fair and bad at times due to heavy summer rains.

Removal of Pavement.—Consisting of asphalt on 8-in. concrete base and brick on 8-in. concrete base. A large portion of this conduit was built in the grass space between the sidewalk and curbing.

Excavation.—The soil consisted of clay of which about 50 per cent had to be braced. There was 600 ft. of trench in rock removed by blasting. The grass sod was removed and rolled up. Where the sod was in poor condition, new sod was laid after the trench was backfilled and tamped.

Laying Conduit.—The conduit was laid by the layer or tier-by-tier method. Three inches of concrete was placed in the bottom of the trench and the first tier laid thereon. A complete description of this method is given on pages 39 and 40.

Concrete.—Pouring the concrete was accomplished by placing a ¼-yd. mixer near the trench and running the concrete into trench with a chute. Water-supply pipe was laid along the curb with valve connections at intervals of 50 to 75 ft. The concrete mixture consisted of one part portland cement, three parts clean sharp sand, and six parts of ½-in. rock.

Hauling Material and Surplus.—All hauling was done with 5-ton trucks and hauled approximately 2 to 4 miles.

Manholes were of the octagonal type (see Fig. 54, page 59).

Analysis and Cost of Labor for Installing a Ten-duct Underground Conduit, Job No. 20

Duct feet	116,500
Trench feet	11,650
Conduit used	Six 4-in. four 4½-in. tile duct
Concrete mixture	1:3:6 portland cement, sand, chat
Concrete envelope	3-in. base, 3-in. sides, 3-in. top and 1½-in. separation
Common labor	9 hr. at 45 to 50 cts. per hour

Man-hours

Item	Total hours	Per trench foot	Per duct foot
Removing paving	771	0.066	006
Excavating	38,324	3.290	329
Laying conduit	9,048	0.776	077
Mixing and pouring concrete	10,021	0.861	086
Backfilling	4,734	0.406	041
Loading and removing surplus dirt	6,303	0.541	054
Hauling material	6,700	0.575	057
Total	75,901	6.515	650

Labor Costs

Item	Totals	Per trench foot	Per duct foot
Removing paving	$ 362.32	$0.030	$0.003
Excavating	16,876.18	1.448	0.144
Laying conduit	4,409.69	0.378	0.038
Mixing and pouring concrete	4,676.80	0.401	0.040
Backfilling	2,197.95	0.188	0.019
Loading and removing surplus dirt	4,620.05	0.396	0.040
Hauling material	4,754.59	0.408	0.041
Total	$37,887.58	$3,249	$0.325

Miscellaneous Data

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Paving removed, square yards	0.31	1143	0.0918	0.0092
Excavating, cubic yards	3.20	5275	0.4527	0.0452
Backfilling, cubic yards	1.20	1829	0.1570	0.0157
Removing surplus dirt, cubic yards	1.34	3446	0.2957	0.0295
Material used, cement	....	3727	0.3199	0.0320
Material used, rock	....	1215	0.1043	0.0104
Material used, sand	....	391	0.0335	0.0034

Approximate amount of concrete, 1,060 cu. yds.

Cost of labor	$ 4.41
Cost of material	6.80
Total	$11.21

Cost of Manholes Constructed in Connection with a Ten-duct Tile Conduit, Job No. 20

Number of manholes	39
Concrete mixture	1:2:4
Common labor	9 hr. at 45 to 50 cts. per hour

Man-hours

Item	Total hours	Per manhole
Removing paving	159	4
Excavating	5,802	149
Setting forms	1,289	33
Mixing and pouring concrete	1,935	49
Removing forms	242	6
Backfilling	473	12
Setting castings	143	4
Making sewer connections	408	10
Hauling surplus dirt	1,143	29
Hauling material	704	18
Total	12,298	314

Labor Costs

Item	Totals	Per manhole
Removing paving	$ 73.91	$ 1.89
Excavating	2,677.71	68.66
Setting forms	602.92	15.46
Mixing and pouring concrete	929.80	23.84
Removing forms	116.32	2.98
Backfilling	216.14	5.54
Setting castings	68.94	1.77
Making sewer connections	194.33	4.98
Hauling surplus dirt	1,036.14	26.57
Hauling material	538.58	13.81
Total	$6,454.79	$165.50

Miscellaneous Data

Item	Per cubic yard	Totals	Per manhole
Pavement removed, square yards	53	138	3.54
Excavating, cubic yards	2.23	1,199	30.74
Material used, cement, cubic yards	....	2,140	54.90
Material used, rock, cubic yards	....	503	12.91
Material used, sand, cubic yards	....	2,015	5.17
Backfilling	0.79	273	7.00
Surplus dirt removed	1.12	926	23.74

Approximate amount concrete used, 530 cu. yd.

Approximate cost material per cubic yard concrete	$6.68
Approximate cost labor per cubic yard concrete	1.75
Total	$8.43

CONSTRUCTION DATA, JOB NO. 21

Laying Conduit.—The conduit was laid by the tier-by-tier method.

Concrete.—Pouring concrete was accomplished by wheeling to the trench for a distance of 100 ft. Due to traffic on the street it was not possible to operate the mixer on the street where the conduit was being installed.

Hauling Material and Surplus.—All hauling was done with 5-ton trucks and hauled not over 1 mile.

Manholes.—A part of this conduit was installed alongside an old duct and the manholes were enlarged. They were partly built under the street-car tracks. There were seven manholes of various sizes. The cost data cover an average of the total.

Analysis and Cost of Labor for Installing a Ten-duct Underground Conduit, Job No. 21

Duct feet	8,285
Trench feet	828.5
Conduit used	Ten 4-in. tile ducts
Concrete mixture	1:3:6 portland cement, sand, and chat
Concrete envelope	3-in. base, 3-in. sides, 3-in. top and 1½-in. separation
Common labor	9 hr. per day at 40 to 45 cts. per hour
Company's trucks	9 hr. per day at $1.58 to $2.10 per hour

Man-hours

Item	Total hours	Per trench foot	Per duct foot
Removing paving	994	1.1998	0.1200
Excavating	3,903	4.7109	0.4711
Laying conduit	679.5	0.8202	0.0820
Mixing and pouring concrete	1,012.5	1.2221	0.1222
Backfilling	736	0.8883	0.0888
Loading and hauling surplus dirt	891.5	1.0760	0.1076
Hauling material	616	0.7435	0.0743
Total	8,832.5	10.6608	1.0660

Labor Costs

Item	Totals	Per trench foot	Per duct foot
Removing paving	$ 409.70	$0.4945	$0.0494
Excavating	1,584.03	1.9119	0.1912
Laying conduit	288.85	0.3486	0.0349
Mixing and pouring concrete	420.33	0.5073	0.0507
Backfilling	315.61	0.3809	0.0381
Loading and hauling surplus dirt	551.43	0.6656	0.0666
Hauling material	411.28	0.4969	0.0496
	$3,981.23	$4.8052	$0.4805

Miscellaneous Data

Item	Per yard	Totals	Per trench foot	Per duct foot
Removing paving	$3.32	123.5	0.1491	0.0149
Excavating	2.84	558	0.6735	0.0674
Backfilling	0.72	403	0.4864	0.0486
Removing surplus dirt	3.55	155	0.1871	0.0187
Material used, cement	.....	355	0.4285	0.0429
Material used, rock	.....	83	0.1002	0.0100
Material used, sand	.....	44	0.0531	0.0053

Approximate amount of concrete used, 98 cu. yd.

Approximate cost of labor per cubic yard of concrete	$4.29
Approximate cost of material per cubic yard of concrete	5.07
Total	$9.36

Cost of Manholes Constructed in Connection with a Ten-duct Underground Tile Conduit, Job No. 21

Number of manholes	7
Average size of manholes	10 by 6 by 9 ft. deep
Concrete mixture	6:2:4 top, 1:3:5 walls
Common labor	9 hr. per day at 40 to 45 cts. per hour

Man-hours

Item	Total hours	Per manhole
Removing paving	501.5	71,643
Excavating	2,819	402,714
Setting forms	689	98,429
Mixing and pouring concrete	926.5	132,357
Setting castings	31.5	4,500
Backfilling	48.5	6,929
Removing forms	147.5	21,071
Making sewer connections	71.5	10,214
Fireproofing water mains	220	31,429
Hauling surplus dirt	565.5	80,786
Hauling material	646.5	92,357
Total	6,667.0	952,429

Labor Costs

Item	Totals	Per manhole
Removing paving	$ 213.92	$ 30.560
Excavating (clay)	1,133.69	161.956
Setting forms	292.85	41.836
Mixing and pouring concrete	394.99	56.427
Setting casting	13.85	1.978
Backfilling	21.51	3.073
Removing forms	63.76	9.109
Making sewer connections	29.13	4.161
Fireproofing water mains	98.05	14.007
Hauling surplus dirt	410.62	58.660
Hauling material	459.03	65.576
Total	$3,131.40	$447.343

CONSTRUCTION DATA

Weather.—Cold and freezing.

Removal of Pavement.—Consisting of brick on 8-in. concrete base. Most of this paving was removed with a portable air compressor and jack hammer.

Excavation.—The soil consisted of clay and fill. Where buildings formerly stood old foundations were encountered while excavating.

CONSTRUCTION DATA, JOB NO. 22

Removal of Pavement.—It was necessary to remove 430 sq. yd. of pavement constructed of sandstone on a concrete base, which required 727 man-hr., or an average of 1.69 man-hr. per square yard, or 470 man-hr. per trench-foot.

Excavation.—The soil consisted of clay with a little sand, and about 150 ft. of the trench was peat; about 100 ft. was in rock, and the balance, about 1,200 ft., was in clay. The trench was excavated so there would be a minimum of 30 in. between the top of the duct structure and street level. Considerable trouble was experienced in excavating portions of the trench due to surface water at a depth of 4 ft.

Laying Conduit.—The conduit was laid by the built-up method, using 1-in. square wooden separators. The joints of the conduit were painted with P & B compound No. 2.

Concrete.—The concrete mixture was 1:7 portland cement and torpedo sand. Mixing was done in a ¼-yd. mixer.

Surplus Earth.—Most of the surplus earth was disposed of by wheeling it in barrows to near-by building lots to be used as filling.

Hauling Material.—All material was hauled in work cars and trucks a distance of approximately 4 miles.

Analysis and Cost of Labor for Installing a Twelve-duct Underground Conduit, Job No. 22

Duct feet	18,564
Trench feet	1,547
Conduit installed	3½-in. socket-fiber conduit, Orangeburg
Concrete mixture	1:7 portland cement and torpedo sand
Concrete envelope	3-in. base, 2-in. sides, 3-in. top, 1-in. separation
Common labor	10 hr. at 20 to 22½ cts. per hour

Man-hours

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Labor removing pavement, square yards	0.583	727	0.470	0.0392
Labor excavating	2.47	1,527	0.987	0.0822
Labor mixing and pouring concrete	12.04	927	0.5992	0.0499
Labor laying conduit	......	255	1.1648	0.0137
Labor backfilling	2.086	753	0.4867	0.0405
Labor removing surplus dirt	2.498	937	0.6057	0.0504
Labor hauling material	......	652	0.4214	0.0351
Labor concreting for paving base	10.39	717	0.4635	0.0386
Total	......	6,495	4.1983	0.3496

Labor Costs

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Cost of removing pavement, square yard	$0.1165	$ 145.40	0.0940	0.0078
Cost of excavating	0.5675	350.74	0.2267	0.0189
Cost of mixing and pouring concrete	2.488	191.61	0.1238	0.0103
Cost of laying conduit	......	53.80	0.0348	0.0029
Cost of backfilling	0.4285	154.72	0.1000	0.0083
Cost of removing surplus dirt	0.510	191.36	0.1237	0.0103
Cost of hauling material	......	173.00	0.1118	0.0093
Cost of concreting for paving base	2.12	146.40	0.0946	0.0079
Total	......	$1,407.03	0.9094	0.0757

Miscellaneous Data

Item	Totals	Per trench foot	Per duct foot
Excavation, cubic yards	618	0.3995	0.0333
Material used, cement conduit, sacks	286	0.1849	0.0154
Material used, sand conduit, cubic yards	40	0.0258	0.0022
Material used, cement paving, sacks	277	0.1791	0.0149
Material used, sand paving, cubic yards	34	0.0220	0.0018
Material used, rock paving, cubic yards	56	0.0362	0.0030
Removal surplus dirt, cubic yards	375	0.2424	0.0202
Backfill surplus dirt, cubic yards	361	0.2333	0.0194
Approximate amount of paving removed, square yards	350	0.8061	0.0671
Approximate amount concrete, cubic yards	77	0.0498	0.0041
Approximate amount concrete paving	69	0.0446	0.0037

Amount of concrete for paving base 69 cu. yd.

Approximate cost of material, cubic yards	$2.231	for paving and conduit.
Approximate cost of labor, cubic yards	4.608	for paving and conduit.
Total	$6.839	

CONSTRUCTION DATA, JOB NO. 23

Weather.—Good.

Removal of Pavement.—Eighty-five square yards of cobblestone pavement on concrete base was removed in 100 man-hr., or an average of 1.18 man-hr. per square yard.

Excavation.—The excavation of this trench was in rock beginning just below the paving base in 6- to 15-in. layers. The rock was removed from the trench by the plug-and-feather method. Explosives could not be used on account of other conduit lines and steam mains close to the trench, which for a great part of the trench distance had to be supported during excavation and construction. The depth of the excavation was 4 ft. and the trench was 24 in. wide.

Laying Conduit.—The conduit was laid by the layer method, with 1 in. of concrete separating the ducts vertically and horizontally. The joints of the conduit were painted with P & B compound No. 2.

Concrete.—The concrete mixture was one part portland cement, three parts sand, and six parts Joplin chat. Mixing was done in ¼-yd. mixer.

Surplus Earth.—The surplus earth and rock from the excavation was hauled with trucks about 2 miles for disposal.

Hauling Material.—All materials for the job were hauled by trucks about 2 miles.

ANALYSIS AND COST OF LABOR FOR INSTALLING A TWELVE-DUCT UNDERGROUND CONDUIT USING THE TIER-BY-TIER METHOD OF CONSTRUCTION, JOB NO. 23

Duct feet	4,740
Trench feet	395
Conduit installed	4½-in. fiber socket-joint Orangeberg
Concrete mixture	1:3:6 portland cement, sand, and chat
Concrete envelope	3-in. base, 3-in. sides, 3-in. top and 1-in. separation
Common labor	9 hr., 45 to 50 cts. per hour.

MAN-HOURS

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Labor removing pavement stone	1.17	99.5	0.252	0.0210
Labor excavating solid rock	8.572	2,066	5.23	0.4359
Labor laying conduit	.....	226	0.572	0.0477
Labor mixing and pouring concrete	4.367	345	0.873	0.0728
Labor backfilling	0.856	137	0.347	0.0289
Labor loading and removing surplus dirt	4.648	376.5	0.953	0.0794
Labor hauling material	.....	293	0.742	0.0618
Total	.....	3,543.0	8.969	0.7475

LABOR COSTS

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Cost of removing paving	$0.84	$ 71.44	$0.181	$0.0151
Cost of excavating rock	3.976	958.34	2.426	0.2022
Cost of laying conduit	.....	97.99	0.248	0.0207
Cost of mixing and pouring concrete	2.035	160.75	0.407	0.0339
Cost of backfilling	0.338	54.08	0.137	0.0114
Cost of loading and hauling surplus dirt	3.193	258.64	0.655	0.0546
Cost of hauling material	.....	206.05	0.522	0.0435
Total	.....	$1,807.29	$4.576	$0.3814

MISCELLANEOUS DATA

Item	Totals	Per trench foot	Per duct foot
Paving removed	85	0.215	0.0179
Excavating	241	0.610	0.0508
Removing surplus dirt	81	0.205	0.0171
Backfilling	160	0.405	0.0338
Material used, cement	110	0.278	0.0232
Material used, sand	57	0.144	0.0120
Material used, rock	29	0.073	0.0061
Approximate amount of concrete used, cubic yards	79	0.200	0.0167

Approximate cost of material per cubic yard	$2.874
Approximate cost of labor per cubic yard	2.035
Total	$4.909

CONSTRUCTION DATA, JOB NO. 24

Weather.—Good.

Labor.—Nine-hour day.

Removal of Pavement.—Brick pavement on a concrete base amounting to 353 sq. yd. was removed in 266 man-hr., or an average of 1.04 man-hr. per square yard.

Excavation.—The earth in which the trench was excavated was of self-supporting clay except in a few patches where it was mixed with quicksand. The dimensions of the trench averaged about 6½ ft. deep and 20 in. wide. A minimum distance of 24 in. between the top of the duct structure and the street level was maintained.

Laying Compound.—The conduit was laid by the built-up method, using 3-in. square concrete separators and a 3-in. envelope. The joints of the conduit were painted with P & B compound No. 2.

Concrete.—The concrete mixture was 1:3:6 portland cement, sand, and Joplin chat. Mixing was done in a ¼-yd. mixer.

Surplus Earth.—Surplus earth was hauled an average of six blocks for disposal.

Hauling Material.—All material was hauled on truck an average of six blocks.

Miscellaneous.—This conduit line crossed under street railway tracks in two places where water and gas mains were encountered and cared for.

ANALYSIS AND COST OF LABOR FOR INSTALLING A TWELVE-DUCT UNDERGROUND CONDUIT, JOB NO. 24

Duct Feet	13,620
Trench feet	1,135
Conduit installed	Twelve 4-in. Harrington-joint fiber Orangeberg
Concrete mixture	1:3:6 portland cement, sand, and chat
Concrete envelope	3-in. base, 3-in. sides, 3-in. top, and 3-in. separation
Common labor	9 hr., 45 to 50 cts. per hour

MAN-HOURS

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Labor removing paving, brick, square yards	1.037	366	0.322	0.0269
Labor excavating clay, and quicksand	6.406	3,043	2.681	0.2234
Labor laying conduit	.....	430	0.379	0.0316
Labor mixing and pouring concrete	6.516	1,297	1.143	0.0952
Labor backfilling	4.608	1,327	1.169	0.0974
Labor loading and removing surplus dirt	4.742	882	0.777	0.0648
Hauling material	.....	593	0.522	0.0435
Total	.....	7,938	6.993	0.5828

LABOR COSTS

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Labor removing paving	$0.5144	$ 181.60	$0.160	$0.0133
Labor excavating	3.20	1,519.95	1.339	0.1116
Labor laying conduit	......	215.65	0.190	0.0158
Labor mixing and pouring concrete	3.30	646.95	0.570	0.0475
Labor backfilling	2.241	645.33	0.569	0.0474
Labor loading and removing surplus dirt	2.259	420.23	0.370	0.0309
Labor hauling material	......	450.40	0.397	0.0331
Total	......	$4,080.11	$3.595	$0.2996

MISCELLANEOUS DATA

Item	Totals	Per trench foot	Per duct foot
Paving removed, cubic yards	353	0.311	0.0259
Excavating, cubic yards	475	0.418	0.0349
Backfilling, cubic yards	288	0.254	0.0211
Removing surplus dirt, cubic yards	186	0.164	0.0137
Material used, cement, sacks	775	0.683	0.0569
Material used, rock, cubic yards	166	0.146	0.0122
Material used, sand, cubic yards	83	0.073	0.0061
Approximate amount of concrete used	196	0.173	0.0144

Approximate cost of labor, cubic yard	$3.30
Approximate cost of material, cubic yard	7.052
Total	$10.352

CONSTRUCTION DATA, JOB NO. 25

Weather.—Good.

Labor.—Nine-hour day.

Removal of Pavement.—Sixty-eight square yards of asphalt pavement on concrete base was removed in 264 man-hr., or at an average of 3.88 man-hr. per square yard.

Excavation.—The excavation for this line was in rock in ledges running from 7 to 15 in. in thickness. The rock was drilled by hand with churn drills, and blasted after 6 P. M. to avoid street and sidewalk traffic. This line passed under street railway tracks and under water and gas mains, necessitating great care when blasting. The water mains and gas mains were covered with sacks filled with sand for protection. The depth of the excavation averaged 6 ft. and the trench was 24 in. wide.

Laying Conduit.—The conduit was laid by the tier-by-tier method, with 1½-in. concrete separation between ducts both vertically and horizontally. The laying of the conduit by this method increased the cost of laying considerably. The joints of the conduit were painted with P & B compound No. 2.

Concrete.—The concrete mixture was 1:3:6 portland cement, sand, and Joplin chat. Mixing was done in a ¼-yd. mixer. A large amount of concrete was handled on this job because after the rock was excavated the trench had very ragged sides, necessitating a large amount of concrete to fill in. Due to traffic, the concrete had to be wheeled 200 ft. uphill.

Surplus Earth.—The rock from this excavation was hauled away, and earth from another conduit job was hauled in for backfill. The surplus rock was hauled about 3 miles for disposal.

Hauling Material.—All materials for this job were hauled about 3 miles.

Analysis and Cost of Labor for Installing a Twelve-duct Underground Conduit, Job No. 25

Duct feet	3,900
Trench feet	325
Conduit installed	Twelve 4-in. fiber duct Orangeberg
Concrete mixture	1:3 : 6, of portland cement, of sand, and of chat
Concrete envelope	3-in. base, 3-in. sides, 3-in. top, 1-in. separation
Common labor	9 hr. at 40 to 50 cts. per hour

Man-hours

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Labor removing pavement, asphalt	3.882	264	0.812	0.0677
Labor excavating solid rock	29.34	2,494	7.674	0.6395
Labor laying conduit	......	348	1.071	0.0892
Labor mixing and pouring concrete	10.32	516	1.588	0.1323
Labor backfilling	5.545	183	0.563	0.0469
Labor loading and hauling surplus dirt	8.038	418	1.286	0.1076
Labor hauling material	......	199½	0.614	0.0512
Total	......	4,422.5	13.608	1.1340

Labor Costs

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Cost of removing pavement	$ 1.659	$ 112.85	$0.347	$0.0289
Cost of excavating	15.02	1,276.65	3.928	0.3273
Cost of laying conduit	....	173.68	0.534	0.0445
Cost of mixing and pouring concrete	5.059	252.97	0.778	0.0649
Cost of backfilling	3.286	108.45	0.334	0.0278
Cost of loading and removing surplus dirt	4.985	259.25	0.798	0.0665
Cost of hauling material	....	134.81	0.415	0.0346
Total	....	$2,318.66	$7.134	$0.5945

Miscellaneous Data

Item	Totals	Per trench foot	Per duct foot
Paving removed, square yards	68	0.209	0.0174
Excavating, cubic yards	85	0.262	0.0218
Removing surplus dirt, cubic yards	52	0.160	0.0133
Backfilling, cubic yards	33	0.102	0.0085
Material used, cement, sacks	198	0.609	0.0508
Material used, sand, cubic yards	25	0.077	0.0064
Material used, rock, cubic yards	48	0.148	0.0123
Approximate amount of concrete used	50	0.154	0.0128

Approximate cost of material used, cubic yards	$ 7.537
Approximate cost of labor used, cubic yards	5.059
	$12.596

Large amount of concrete due to condition of trench.

CONSTRUCTION DATA, JOB NO. 26*

Weather.—Good.

Labor.—Nine-hour day.

Removal of Pavement.—Fifty-eight square yards of asphalt pavement on concrete base were removed in 196 man-hr., or an average of 3.38 man-hr. per square yard.

Excavation.—The trench excavation was in solid limestone rock which was close to the street surface. It was necessary to excavate the trench to a depth of 6 to 7 ft. About 100 ft. of the trench was drilled and blasted, while 145 ft. had to be excavated by the plug-and-feather method, it being impossible to use explosives in this section because of danger to adjacent water and gas mains. The rock had to be tunneled under street railway tracks. While the trench was being excavated, it was necessary to dispose of the rock as it was taken from the trench by loading it on wheelbarrows and hauling it about 100 ft., where it was loaded on motor trucks and hauled away for disposal. It was necessary to do this to prevent blocking traffic by motor trucks alongside the trench.

Laying Conduit.—The conduit was laid by the built-up method, using 3-in. square concrete separators. It will be noted that the bottom tier of ducts are 4½-in. inside diameter, and the middle and upper tiers are 4-in. inside diameter; the 4½-in. ducts being for transmission, and the 4-in. ducts for distribution. The joints of the conduit were painted with P & B compound No. 2. Laying conduit was slow due to the many obstructions and the depth of the trench. It was necessary at times to divide the conduit line, installing part of the conduit under the obstruction, and the other part of the conduit over the obstruction.

Concrete.—The concrete mixture was 1:3:6 portland cement, sand, and Joplin chat. Mixing was done in ¼-yd. mixer which was stationed at one end of the job, and could not be moved on account of traffic conditions. All mixed concrete had to be wheeled an average of over 100 ft.

Backfilling.—The work being done in the downtown section, it was necessary to haul away all surplus rock excavated and haul earth from another conduit job for backfill.

* This short conduit line was constructed in the downtown business district, and obstacles of all kinds were encountered in the construction, as will be noted by the following construction notes.

Surplus Earth.—As stated above, while the trench was being excavated the rock as taken from the trench had to be hauled by wheelbarrow about 100 ft., where it was loaded on a motor truck and hauled away for disposal, the average haul being about 3 miles.

Hauling Material.—All material for this job was hauled by truck about 3 miles.

ANALYSIS AND COST OF LABOR FOR INSTALLING A TWELVE-DUCT UNDERGROUND CONDUIT, JOB NO. 26

Duct feet	2,940
Trench feet	245
Conduit installed	Four 4½-in. and eight 4-in. fiber duct Orangeberg
Concrete mixture	1:3:6, portland cement, sand, and chat
Concrete envelope	3-in. base, 3-in. sides, 3-in. top, and 3-in. separation
Common labor	9 hr. at 45 to 50 cts. per hour

MAN-HOURS

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Labor removing pavement	3.379	196	0.80	0.0667
Labor excavating solid rock	38.59	2,470	10.08	0.8401
Labor laying conduit	....	250	1.02	0.0850
Labor mixing and pouring concrete	7.78	389	1.59	0.1323
Labor backfilling	4.833	174	0.71	0.0592
Labor loading and removing surplus dirt	13.82	387	1.58	0.1316
Labor hauling material	....	141	0.58	0.0480
Total	....	4,007	16.36	1.3629

LABOR COSTS

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Cost of removing pavement, square yards	$ 1.671	$ 96.94	$0.396	$0.0330
Cost of excavating, cubic yards	19.14	1,224.86	5.00	0.4166
Cost of laying conduit	.....	115.53	0.472	0.0393
Cost of mixing and pouring concrete	3.614	180.69	0.738	0.0615
Cost of backfilling	2.614	94.10	0.384	0.0320
Cost of loading and removing surplus dirt	8.275	231.70	0.946	0.0788
Cost of hauling material	....	114.92	0.469	0.0391
Total	....	$2,058.74	$8.405	$0.7003

MISCELLANEOUS DATA

Item	Totals	Per trench foot	Per duct foot
Paving removed, square yards	58	0.237	0.0197
Excavating, cubic yards	64	0.261	0.0218
Removing surplus dirt, cubic yards	28	0.114	0.0095
Backfilling	36	0.147	0.0122
Material used, cement, sacks	159	0.649	0.0541
Material used, sand, cubic yards	21	0.086	0.0071
Material used, rock, cubic yards	38	0.155	0.0129
Approximate amount of concrete used, cubic yards	50	0.204	0.0170

Approximate cost of material, cubic yards	$6.061
Approximate cost of labor, cubic yards	3.614
	$9.675

CONSTRUCTION DATA, JOB NO. 27*

Weather.—Good.

Labor.—Nine-hour day.

Removal of Pavement.—Brick pavement on concrete base amounting to 461 sq. yd. was removed, requring 896 man-hr. or an average of 1.94 man-hr. per square yard.

Excavation.—It was necessary to go quite deep on account of obstructions encountered all along the route. The average depth of the trench was 10 ft., and in about 800 ft. of the trench a former street grade with brick pavement on concrete base was encountered about 3 ft. below the present street grade. It was necessary to remove this old pavement to excavate a trench of sufficient depth. The removal of this old pavement is charged to excavation. The soil was self-supporting, but the conduit line crossed under three street intersections where there were railway crossings, making it necessary to go under four tracks at each intersection. This contributed greatly to high cost of excavation.

Laying Conduit.—The conduit was laid by the built-up method, with 3-in. concrete separators both horizontally and vertically, with a 3-in. concrete envelope all around. The joints of the conduit were painted with P & B compound No. 2.

Concrete.—The concrete mixture was 1:3:6 portland cement, sand, and Joplin chat. Mixing was done in ¼-yd. mixer.

Surplus Earth.—Disposal of surplus earth was done with 5-ton trucks at a distance of approximately 1 mile.

Hauling Material.—All materials for this job were hauled by 5-ton trucks a distance of about 1 mile.

* This job was constructed complete in 21 days. Owing to a late decision concerning choice of route, the substation to which the line was being constructed was almost ready for operation before the underground work started. Thirty days were given to finish the conduit work complete, and it was necessary to work overtime every day, which ran the cost of the job up considerably.

ANALYSIS AND COST OF LABOR FOR INSTALLING A TWELVE-DUCT UNDERGROUND CONDUIT, JOB NO. 27

Duct feet	21,530
Trench feet	1,770
Conduit used	4½-in. fiber Orangeberg
Concrete mixture	1:3:6, portland cement, sand, and chat
Concrete envelope	3-in. base, 3-in. sides, 3-in. top, and 3-in. separation
Common labor	9 hr. at 45 and 50 cts. per hour

MAN-HOURS

Item	Total hours	Per trench foot	Per duct foot
Removing paving, brick	895.5	0.5056	0.0414
Excavating	6,256.	3.5344	0.2905
Laying conduit	1,095.5	0.619	0.0508
Mixing and pouring concrete	1,722.	0.9728	0.0800
Backfilling	981.5	0.5545	0.0456
Loading and removing surplus dirt	1,783.5	1.0762	0.0828
Hauling material	773.	0.4367	0.0360

LABOR COSTS

Item	Totals	Per trench foot	Per duct foot
Removing paving	$ 457.31	$0.2583	$0.0212
Excavating	2,760.69	1.5597	0.1282
Laying conduit	474.86	0.2683	0.0225
Mixing and pouring concrete	793.97	0.4486	0.0370
Backfilling	460.26	0.2600	0.0214
Loading and removing surplus dirt	1,168.00	0.6600	0.0542
Hauling material	564.68	0.3190	0.0262
Total	$6,679.77	$3.7739	$0.3107

MISCELLANEOUS DATA

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Paving removed, square yards	0.99	461	0.2604	0.0214
Excavating, cubic yards	2.51	1,101	0.6220	0.0511
Backfilling, cubic yards	0.65	708	0.4000	0.0330
Removing surplus dirt, cubic yards	2.98	393	0.2220	0.0182
Material used, cement, sacks	....	1,159	0.6548	0.0538
Material used, rock, cubic yards	....	323	0.1830	0.0150
Material used, sand, cubic yards	....	161	0.0915	0.0075
Approximate amount of concrete used cubic yards	....	385		

Cost of labor	$2.06
Cost of material	5.51
	$7.57

Cost of Manholes Constructed in Connection with a Twelve-duct Underground Conduit, Job No. 27

Number of manholes	6
Concrete mixture	1:2:4
Common labor	9 hr. at 45 to 50 cts. per hour

Man-hours

Item	Total hours	Per manhole
Removing, paving, square yards	128	21.33
Excavating	1,229	204.83
Setting forms	592	98.67
Mixing and pouring concrete	627.5	104.60
Removing forms	101	16.82
Backfilling	54.5	9.08
Removing surplus dirt	146	24.33
Hauling material	110	18.33
Setting castings	63.5	10.58

Labor Costs

Item	Totals	Per manhole
Removing paving	$59.00	$9.83
Excavating	592.43	98.74
Setting forms	301.21	50.20
Mixing and pouring concrete	295.42	49.24
Removing forms	47.14	7.86
Backfilling	26.01	4.23
Removing surplus dirt	141.47	23.58
Hauling material	88.53	14.755
Setting castings	31.01	5.17
Total	$1,582.22	$263.605

Miscellaneous Data

Item			
Pavement removed, square yards	0.84	69.6	11.6
Excavation, square yards	2.91	203	34
Material used, cement, sacks	....	364	60.7
Material used, sand, cubic yards	....	63	10.5
Material used, rock, cubic yards	....	153	25.5
Backfilling	0.96	27	4.5
Surplus dirt removed	0.80	176	30.3
Approximate amount concrete used, square yards	....	91	15.1

Approximate cost material per cubic yard concrete	$ 8.82
Approximate cost labor per cubic yard concrete	3.27
Total	$12.09

CONSTRUCTION DATA, JOB NO. 28

This conduit was constructed in a congested district. Excavation was in clay, a third of the distance, the balance being in solid rock which was drilled with jack hammer and blasted with 40 per cent dynamite. There were a great many obstructions and the average depth of trench was 8 ft. The formation was 4 ft. wide and 4 ft. high. The street was paved with 8-in. concrete base and asphalt surface.

Laying Conduit.—The conduit was laid by the built-up method using 3-in. square concrete separators in bottom of trench, which were leveled to grade with surveyor's level. The conduit bank was then built up using 3-in. separators between ducts and 3-in. envelope.

Concrete.—Was a 1:3:6 mixture of portland cement, clean sharp sand, and ½-in. rock.

Surplus.—Rock was hauled away and clay was used for backfill.

Analysis and Cost of Labor of a Sixteen-duct Underground Conduit Line, Job No. 28

Duct feet	11,608
Trench feet	725.5
Conduit used	Sixteen 4-in. fiber conduit
Concrete mixture	¾:2:5 cement, sand and chat
Concrete envelope	3-in. top, 3-in. sides, 3-in. separation and 3-in. bottom
Common labor	9 hr. per day at 40 to 45 cts. per hour

Man-hours

Item	Total hours	Per trench foot	Per duct foot
Removing paving (asphalt)	790.5	1.0896	0.0681
Excavating (rock and clay)	10,178	14.0289	0.8768
Laying conduit	282.5	0.3894	0.0243
Mixing and pouring concrete	468.5	0.6458	0.0404
Backfilling	928.5	1.2798	0.0800
Hauling material	553.5	0.7629	0.0477
Removing surplus dirt	840.5	1.1585	0.0724
Total	14,042.0	19.3549	1.2097

Labor Costs

Item	Totals	Per trench foot	Per duct foot
Removing paving (asphalt)	$ 327.41	$0.4513	$0.0282
Excavating (rock and clay)	4,193.53	5.7802	0.3613
Laying conduit	120.54	0.1662	0.0104
Mixing and pouring concrete	196.10	0.2703	0.0169
Backfilling	379.75	0.5234	0.0327
Hauling material	425.22	0.5861	0.0366
Removing surplus dirt	673.14	0.9278	0.0580
Total	$6,315.69	$8.7053	$0.5441

Material and Miscellaneous Data on a Sixteen-duct Underground Fibre Conduit Line (725.5 Ft.)

Materials	Amounts	Totals	Per trench foot	Per duct foot
Cement	534 sacks at $0.55	$ 293.70	$ 0.4048	$0.0253
Rock	135 yd. at $2.00	270.00	0.3722	0.0233
Sand	55 yd. at $2.00	110.00	0.1516	0.0095
4-in. fiber conduit	0.1205 ft.	1,398.76	1.9280	0.1205
28-in. separators	0.086 each	176.58	0.2434	0.0152
Paint and twine		31.20	0.0430	0.0027
Lumber		48.12	0.0663	0.0041
Gas and oil		43.90	0.0605	0.0038
Tools and tools repaired		72.07	0.0993	0.0062
Miscellaneous		36.84	0.0508	0.0032
Total		$2,481.17	$ 3.4199	$0.2138
Total cost of labor		$ 6,324.91	$ 8.7180	$0.5449
Total cost of material		2,481.17	3.4199	0.2138
		8,806.08	12.1379	0.7587
Total cost of repaving		1,812.10	2.4977	0.1561
Total		$10,618.18	$14.6356	$0.9148

Miscellaneous Data

Item	Cost per yard	Totals	Per trench foot	Per duct foot
Removing paving	$1.74	188	0.2591	0.0162
Excavating	6.93	590.1	0.8134	0.0508
Backfilling	1.01	375	0.5169	0.0323
Hauling surplus dirt	1.87	360	0.4962	0.0310
Material used, cement, sacks		534	0.7360	0.0460
Material used, rock, yards		135	0.1861	0.0116
Material used, sand, yards		55	0.0758	0.0047

Approximate amount of concrete used 145 cu. yd.	
Approximate cost of labor per cubic yard concrete	$1.42
Approximate cost of material cubic yard concrete	4.65
Total	$6.07

CONSTRUCTION COST DATA, JOB NO. 29

Brick paving and excavating was clay. There were a large number of obstructions and conduit was built in a narrow alley. There was considerable bad weather during the time this conduit was installed. This conduit was installed by the built-up method and concrete poured all at one time. The depth was 8.6 ft.

Analysis and Cost of Labor, a Twenty-eight-duct Underground Conduit Line, Job No. 29

Duct feet	4,808
Trench feet	136
Conduit used	Twenty-eight 4-in. and 4½-in. fiber conduit
Concrete mixture	¾ :2:5 cement, sand, and chat
Concrete envelope	3-in. bottom, 3-in. side, 3-in. separation, and 3-in. top
Common labor	9 hr. per day at 40 to 45 cts. per hour

Man-hours

Item	Total hours	Per trench foot	Per duct foot
Removing paving	76.5	0.5625	0.0201
Excavating	1,824.5	13.4154	0.4791
Laying conduit	112.	0.8235	0.0294
Mixing and pouring concrete	180.5	1.3272	0.0474
Backfilling	112.5	0.8272	0.0295
Hauling material	269	1.9706	0.0704
Removing surplus dirt	649.5	4.7757	0.1706
Total	3,223.5	23.7021	0.8465

Labor Costs

Item	Totals	Per trench foot	Per duct foot
Removing paving	$ 32.93	$ 0.2421	$0.0087
Excavating	703.98	5.1697	0.1846
Laying conduit	48.75	0.3585	0.0128
Mixing and pouring concrete	75.33	0.5539	0.0198
Backfilling	47.75	0.3511	0.0125
Hauling material	190.27	1.3990	0.0500
Removing surplus dirt	436.40	3.2089	0.1146
Total	$1,534.51	$11.2832	$0.4030

ENDLESS-CHAIN TYPE TRENCH EXCAVATOR

The machine for which the following cost records have been made is of the endless-chain type with caterpillar tread, and is equipped with a four-cylinder 48-hp. motor, 600 r.p.m. With this machine dirt can be thrown to either the right or the left as required, the extreme possible depth of the trench being 23 ft. and the extreme width 39-in. It has a traveling speed on the road of 80 ft. per minute and four digging speeds.

The figures from which the cost sheets have been made up are based on the following: Figuring the initial cost of the machine at $12,000, depreciation has been based on that amount extending over a period of 10 years allowing 310 working days per year. Interest earned by depreciation reserve has also been allowed at the rate of 6 per cent per annum. No cost for maintenance or repairs has been allowed as tests were made over a short period of time and only the actual working time of the machine was taken into consideration, in this case there being no delay. The machine was excavating on a slight grade in plain dirt, the street never having been paved. The buckets on the chain are on 4.5 ft. centers, the total number in this case being 13. The average speed is 30 buckets per minute. The size of each bucket is 1.5 ft. wide, 6 in. deep, and 1.7 ft. in length. The gasoline consumption is figured on the basis of 3 gal. per hour and oil at the rate of 6 qt. per 8 hr. Three men are required to operate the machine—the operator, and two laborers; one to clean up the loose dirt in the bottom of the trench and one the loose dirt on top. Common labor is figured at $0.55 per hour and the operator's time at $1 per hour.

It will be noticed in the accompanying cost sheets A and B that there is considerable difference in the trench feet excavated while the time was approximately the same. This is due to the difference in soil, which in the second case was very much harder. No obstructions were encountered in either case.

EXCAVATING—A

Length of trench excavated	179 ft.
Width of trench	2 ft.
Depth of trench	9 ft., 4 in.
Soil	light clay
Actual working time of machine	2 hr.
Total amount of dirt removed	122.61 cu. yd.

COST OF OPERATION

Depreciation on $12,000 in 10 years for 2 hr. at 49 cts. per hour	$0.98
Average interest 6 per cent	0.31
Maintenance and repairs	0.00
Gasoline and oil	1.42
Labor operator, 2 hr. at $1 per hour	2.01
Common labor, 2 men, 3 hr. 40 min. at 55 cts. per hour	2.02
Foreman, 2 hr. at 79¼ cts. per hour	1.46
Cost of operation for 2 hr	$8.20

Cost of excavating per trench foot	179 ft. at $8.20	0.04581 ct.
Cost of excavating per cubic yard of dirt	122.61 at $8.20	0.06688 ct.
Average number of cubic yards per hour	89.5	
Average number of cubic yards per minute	1.4916	

THE BUCKET OR DIPPER TYPE

The machine on which the following cost records have been made is the No. 1 caterpillar type equipped with a 35-hp., four-cylinder gasoline motor automatically controlled by a governor, operating at a speed of 1,200 r.p.m. under load. The bucket or dipper is of ½-yd. capacity, runs out from the crane empty and digs on the return stroke. The bucket is 24 in. wide, 24 in. deep, and 36 in. long. From the highest point on the crane to the ground is 10 ft. 5 in. The extreme outside width is 9 ft. 11 in. the width of the crane body 6 ft., and the weight approximately, 2,400 lb. The traveling speed 70 f.p.m. The boom and mast revolve while the cab is stationary. The maximum depth of trench possible to dig behind the machine is 17 ft., beside the machine 9 ft. The clearance necessary for dumping into trucks is 8 ft. The maximum grade for satisfactory operation is 20 per cent.

Gasoline and Oil Consumption.—The gasoline consumption averages 2 gal. per hour and the oil consumption about 1 qt. per day. The cost of operation in the following reports has been based on these figures.

Excavating.—After the trench has been lined out and plainly marked, a crew of men are then set to work excavating for obstructions which in this case were mainly 3/4-in. water and 1 1/4-in. gas services. A hole is dug directly over the pipe and down to it, this being done to make the pipe readily visible and prevent the machine from tearing it out. Excavating with the ditcher can be done within approximately 2 ft. of the pipe on each side, the balance being taken out by hand. Four men are required while the machine is digging. These are the operator who handles the bucket, one man in the bottom, one on top of the trench shoveling away the loose dirt and one man who measures the depth of the trench and keeps the operator informed. Holes 1 ft. deep and 3 ft. long are dug in the bottom of the trench at every joint of pipe to make room for sealing and leading. The machine cuts a fairly clean ditch and is capable of digging so close to grade for this kind of work that very little if any dirt at all remains to be taken out by hand.

Excavating—B

Length of trench	760 ft.
Width of trench	2.2 ft.
Depth of trench	4.2 ft.
Soil	light clay
Actual working time of machine	16 hr.
Total amount of dirt removed	258.77 cu. yd.

Cost of Operating

Depreciation on $5,500 in 5 yr. for 16 hr. at 44½ cts. per hour	$ 7.13
Average interest 6 per cent at 0.0678 per hour for 16 hr	1.08
Maintenance and repairs	0.00
Gasoline and oil at 15 cts. per gallon	5.45
Labor operator 16 hr. at $1 per hour	16.00
Common labor . . . 44 hr. at 55 cts. per hour	24.20
Foreman . . . 11 hr. at 79¼ cts. per hour	12.72
Cost of operation for 16 hr	$66.58

Cost of excavating per trench foot	760 ft. at $66.58	0.0876 ct.
Cost of excavating per cubic yard	258.77 at $66.58	0.2572 ct.
Average number cubic yards per hour		16.173
Average number cubic yards per minute		0.2695

Cost of Excavating

Length of trench	339 ft.
Width of trench	2.6 ft.
Depth of trench	5.5 ft.
Soil	light clay
Actual working time of machine	8 hr. 30 min.
Total amount of dirt removed	179.54 cu. yd.

Cost of Operation

Depreciation on $5,500 in, 5 years for 8 hr. 30 min. at 44½ cts. per hour	$ 3.78
Average interest 6 per cent at 0.0678 per hour for 8 hr. 30 min	0.57
Maintenance and repairs	0.00
Gasoline and oil at 15 cts. per gallon	3.05
Labor operator 8½ hr. at $1 per hour	8.50
Common labor, three men, 27½ hr. at 55 cts. per hour	14.02
Foreman 6 hr. at 79¼ cts. per hour	4.75
Cost of operation for 8½ hr	$34.67

Cost of excavating per trench foot	339 ft. at $34.67	0.1022 ct.
Cost of excavating per cubic yard of dirt	179.54 at $34.67	0.1931 ct.
Average number of cubic yards dirt per hour		21.12
Average number of cubic yards dirt per minute		0.352

CHAPTER VI

TRANSMISSION AND DISTRIBUTION CONDUITS

The question of separating transmission cables from distribution cables by constructing separate conduits and manholes for each system, or separate conduits and manholes for certain groups of transmission cables or distribution cables to prevent complete failure of power between power house and substation, has presented itself to many electric service companies.

It has been the experience of several companies in the past to have a manhole fire, or a failure of a cable in a duct, cause the loss of several cables and necessitate shutting down a substation

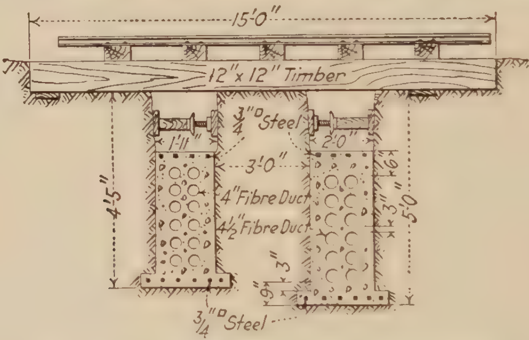


FIG. 101.—Transmission and distribution conduit.

until repairs could be made on the cables feeding the substation. This trouble can be eliminated by building two conduits and installing one feeder in each of the conduits, thus separating the two feeders. They may be built over the same route or over separate routes.

Heat Radiation.—There have been many cases of excessive heating in conduits due to heavily loaded cables, steam mains, and other heavily loaded conduits crossing or running parallel to conduit. These cases have been temporarily taken care of by flooding the conduits with water or soaking the ground with water. In other places blowers were installed to force air through the conduit and thus keep the temperature down within safe

limits. This, however, is necessary only during the hot summer months and not during the winter months. The carrying capacity of cables is less in hot weather than in cold weather.

A study of the kind of soil in which the conduit is to be installed should be made to ascertain its heat-radiation value. It was found that where soils became very dry it acts as an insulator and confines the heat in the duct, while if the soil is kept wet or moist, the radiation is good. In some cities it is possible to construct conduits in the grass space between the sidewalk and curb. This is a very good location for conduit as the cost of paving is eliminated and moisture from rain and sprinkling is continuous except in very dry weather, when sprinkling will not penetrate the earth to the conduit.

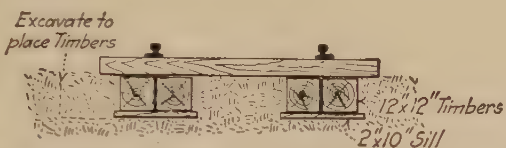


FIG. 102.—Showing method of support for railroad tracks during construction.

The laying of conduit in cinders or ashes should be avoided. Also sand or sandy soil when dry and heated is an insulator and will not radiate heat.

It is evident that no standard rule which would apply to all cases can be considered in regard to the carrying capacity. It is therefore necessary to consider very carefully the location of conduit when determining the size of cables. It is evident, taking into consideration the above, that the conduit should be designed to take care of the required load rather than that a cable should be designed for the conduit.

The question of cost enters into the problem here. An eight-duct conduit 2 ft. wide and 4 ft. high is the most practical from the standpoint of cost and heat radiation. A ten- or even twelve-duct conduit, however, can be built for very little extra expense and here the question of proper separation between ducts should be taken into consideration, as this will help heat radiation and add very little to the total cost of conduit.

When the investment in conduit is considered compared with that of cable, it seems that at times too much emphasis is put on the high cost of conduit construction. For example, say an eight duct conduit is constructed for $6 per trench foot with the eight-

cables installed costing at least $20 per trench foot. The life of the cables depends upon the proper loading to a certain extent, but without the proper conduit construction the cable will have short life. A set of tables of the proper spacing of conduits cannot be given for general practice, due to the many local conditions which enter into the problem. Investigations by one company showed that the temperature elevation of the ground at conduit depth did not entirely disappear until a distance of 30 ft. from the conduit line was reached. At a distance of 15 ft. from the conduit, however, the temperature elevation of the earth is small, being approximately 5 per cent of that immediately next to conduit. Large size ducts should be used to give good ventilation and a limited number of ducts in one conduit. Generous separation between ducts should be allowed, at least 3 inches, the conduit to be constructed two ducts wide so that every duct will make contact with the earth on one side. This is the type construction that will make possible good operation of two conduits quite close together.

CONSTRUCTION DATA, JOB NO. 30

Weather.—Good.

Labor.—Nine-hour day.

A conduit consisted of two separate conduit runs built at the same time, with a separation of 3 ft. between the sides of the trenches. One run consisted of twelve 4½-in. inside diameter fiber ducts for 13,200-volt transmission cables and the other, twelve 4-in. inside diameter fiber ducts for 4,000-volt distribution cables. Each run was provided with separate manholes as shown in Fig. 103. At one point the trenches passed under 15 main-line steam railroad tracks (see Figs. 101, 102 and 105 showing a plan and details of the construction employed at this point). While excavating under the 15 tracks (see Fig. 104 double-tile conduit), each track was supported in the following manner:

Ditches 2 ft. wide and 12 in. deep were dug under each end of the ties for a distance of 15 ft., paralleling the rails. Two 12- by 12-in. yellow-pine timbers, 15 ft. long, were set under each rail. These timbers were properly tamped. After five tracks were timbered in this manner the trench work was begun, and supporting the balance of the tracks in a like manner was continued. At this point the freight traffic was very heavy, and great many delays were caused by trains blocking the work. The trenches were braced with stringers and trench jacks. Many long trains of coal, lumber, structural steel, etc., passed over the

double trench, and the men working under the tracks continued their labor without mishap of any kind. The concrete and other material involved in the job at this point were conveyed in wheelbarrows on plank runways laid over the rails, a watchman being

FIG. 103.—Manholes for two duct lines.

FIG. 104.—Single tile construction, two duct lines being built at once.

employed to give a signal when a train was near, so that the men could be warned and the planks removed. When the work had progressed toward the center of the 15 tracks, a concrete mixer was put up on the viaduct that crosses the tracks at this point,

and a concrete chute 40 ft. long was constructed to carry concrete to the trench. As shown in Fig. 101, the bottom or base for the conduit is 9 in. thick, and has six ¾-in. square reinforcing bars. After the conduit was built up and concrete was poured, four additional ¾-in. square reinforcing bars were laid in the top concrete which was 6 in. in thickness over the ducts. Thirty-six inches of clearance between the top of the duct structure and the railroad ties was maintained. The average depth of the trench at this point was about 8 ft. Most of the surplus earth had to be handled several times before it finally got into trucks and was hauled away for disposal.

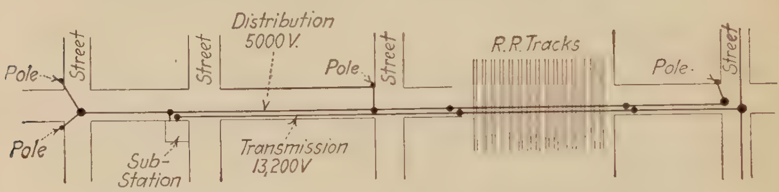


FIG. 105.—Map of transmission and distribution duct line.

Removal of Pavement.—Only 41 sq. yd. of brick pavement on concrete base had to be removed. This required 54 man-hr., or an average of 1.32 man-hr. per square yard.

Excavation.—The soil in which the trenches were excavated was clay, and at a depth of 7 ft. a very wet mixture of clay and quicksand. There were several heavy rains while the excavation work was in progress, but covering the trench at night with planks and banking the edges with earth excluded rain water.

Laying Conduit.—The conduit was laid by the built-up method using 3-in. concrete separators both vertically and horizontally between the ducts, and a 3-in. concrete envelope surrounding them except at the point where the two lines ran under the 15 main-line railroad tracks. The joints of the conduit were painted with P & B compound No. 2.

Concrete.—The concrete mixture was 1:3:6 portland cement, sand, and crushed rock. Mixing was done in a ¼-yd. mixer.

Surplus Earth.—The surplus earth was hauled with trucks not over four blocks. Where the conduit line ran under the 15 railroad tracks the surplus earth had to be handled several times before it finally got into trucks and was hauled away for disposal.

Hauling Material.—All materials for this work were hauled with trucks an average of about four blocks.

Analysis and Cost of Labor for Installing Two 12-duct Lines Built at One Time 3 Ft. Apart, One for Transmission, 4½-in. Socket Joint, and 4-in. Harrington Joint for Distribution
This Data Covers Field Work Only

Duct feet	14,760
Trench feet	615
Conduit installed	Twelve 4-in. fiber Harrington joint and twelve 4½-in. socket
Concrete mixture	1:3:6, portland cement, sand, and of rock
Concrete envelope	3-in. base, 3-in. sides, 3-in. top, and 3-in. separation
Common labor	9 hr. at 45 to 50 cts. per hour

Man-hours

Item	Per cubic yard	Total hours	Per trench foot	Per duct foot
Labor removing paving brick	1.333	54	0.088	0.0036
Labor excavating	6.00	3,353	5.452	0.2272
Labor laying conduit	.....	585	0.951	0.0396
Labor mixing and pouring concrete	5.176	1,501	2.441	0.1017
Labor backfilling	5.963	1,777	2.889	0.1204
Labor loading and removing surplus dirt	3.525	913	1.484	0.0619
Labor hauling material	.....	1,248	2.029	0.0846
Total	.....	9,431	15.334	0.6390

Labor Costs

Item	Per cubic yard	Totals	Per trench foot	Per duct foot
Labor removing paving	$0.553	$ 22.40	$0.036	$0.0015
Labor excavating	2.957	1,653.03	2.688	0.1120
Labor laying conduit	.....	292.15	0.475	0.0198
Labor mixing and pouring concrete	2.525	732.26	1.191	0.0496
Labor backfilling	1.926	574.01	0.933	0.0389
Labor loading and removing surplus dirt	2.378	616.00	1.002	0.0417
Labor hauling material	.....	387.56	0.630	0.0263
Total	.....	$4,277.41	$6.955	$0.2898

Miscellaneous Data

Item	Totals	Per trench foot	Per duct foot
Paving removed, square yards	40.5	0.066	0.0027
Excavation, cubic yards	559	0.909	0.0379
Material used, cement, sacks	885	1.439	0.0600
Material used, sand, cubic yards	90	0.146	0.0121
Material used, rock, cubic yards	179	0.291	0.0196
Approximate amount concrete, cubic yards	290	0.472	0.0175
Approximate amount surplus dirt, cubic yards	259	0.421	0.0202
Approximate amount backfilling, cubic yards	298	0.285	

Approximate cost of material per cubic yard	$5.24
Approximate cost of labor per cubic yard	2.525

TABLE A.—THEORETICAL AMOUNTS OF CONCRETE REQUIRED PER 100 TRENCH FT. OF 3-IN. INSIDE DIAMETER FIBER CONDUIT WITH 3-IN. CONCRETE BASE, 3-IN. CONCRETE TOP, 3-IN. CONCRETE SIDES; CONCRETE SEPARATION, 1 IN., 1½ IN., 2 IN., 2½ IN., 3 IN.

Ducts	Wide High	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
4	2 by 2	4.05	4.41	4.80	5.19	5.60
6	2 by 3	5.18	5.78	6.42	7.08	7.77
8	2 by 4	6.30	7.15	8.05	8.98	9.95
9	3 by 3	6.58	7.55	8.58	9.65	10.79
10	2 by 5	7.42	8.52	9.67	10.87	12.13
12	2 by 6	8.55	9.89	11.30	12.77	14.30
12	3 by 4	7.97	9.31	10.73	12.23	13.80
14	2 by 7	9.67	11.26	12.93	14.67	16.48
15	3 by 5	9.37	11.08	12.88	14.80	16.56
16	4 by 4	9.64	11.47	13.41	15.48	17.65
18	3 by 6	10.76	12.84	15.05	17.38	19.84
20	4 by 5	11.31	13.63	16.10	18.74	21.52
21	3 by 7	12.16	14.61	17.20	19.95	22.85
24	3 by 8	13.56	16.37	19.36	22.53	25.87
24	4 by 6	12.98	15.79	18.79	21.99	25.37

TABLE B.—THEORETICAL AMOUNTS OF CONCRETE REQUIRED PER 100 TRENCH FT. OF 3½-IN. INSIDE DIAMETER FIBRE CONDUIT WITH 3-IN. CONCRETE BASE, 3-IN. CONCRETE TOP, 3-IN. CONCRETE SIDES; SEPARATION OF DUCTS, 1 IN., 1½ IN., 2 IN., 2½ IN., 3 IN.

Ducts	Wide High	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
4	2 by 2	4.49	4.88	5.29	5.70	6.13
6	2 by 3	5.77	6.43	7.11	7.82	8.55
8	2 by 4	7.05	7.98	8.93	9.93	10.96
9	3 by 3	7.38	8.43	9.54	10.69	11.90
10	2 by 5	8.34	9.52	10.75	12.04	13.37
12	2 by 6	9.62	11.07	12.58	14.15	15.79
12	3 by 4	8.97	10.42	11.96	13.56	15.25
14	2 by 7	10.90	12.61	14.40	16.26	18.20
15	3 by 5	10.58	12.43	14.38	16.44	17.60
16	4 by 4	10.90	12.88	14.98	17.20	19.53
18	3 by 6	12.18	14.43	16.80	19.31	21.95
20	4 by 5	12.81	15.33	18.00	20.83	23.82
21	3 by 7	13.78	16.42	19.23	22.18	25.29
24	3 by 8	15.38	18.42	21.65	25.06	28.64
24	4 by 6	14.74	17.79	21.03	24.47	28.10

TABLE C.—THEORETICAL AMOUNTS OF CONCRETE REQUIRED PER 100 TRENCH FT. OF 4-IN. INSIDE DIAMETER FIBER CONDUIT WITH 3-IN. CONCRETE BASE, 3-IN. CONCRETE TOP, 3-IN. CONCRETE SIDES; SEPARATION OF DUCTS, 1 IN., 1½ IN., 2 IN., 2½ IN., 3 IN.

Ducts	Wide High	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
4	2 by 2	4.95	5.36	5.79	6.24	6.70
6	2 by 3	6.39	7.09	7.82	8.57	9.35
8	2 by 4	7.84	8.82	9.84	10.90	12.00
9	3 by 3	8.20	9.34	10.52	11.75	13.04
10	2 by 5	9.28	10.55	11.86	13.23	14.65
12	2 by 6	10.72	12.27	13.88	15.56	17.30
12	2 by 4	10.02	11.58	13.22	14.93	16.72
14	2 by 7	12.17	14.00	15.90	17.89	19.95
15	3 by 5	11.83	13.82	15.91	18.11	20.41
16	4 by 4	12.20	14.34	16.60	18.97	21.45
18	3 by 6	13.65	16.07	18.62	21.30	24.10
20	4 by 5	14.38	17.10	19.97	23.00	26.18
21	3 by 7	15.46	18.31	21.32	24.48	27.80
24	3 by 8	17.27	20.55	24.02	27.66	31.48
24	4 by 6	16.56	19.86	23.35	27.03	30.90

TABLE D.—THEORETICAL AMOUNTS OF CONCRETE REQUIRED PER 100 TRENCH FT. OF 4½-IN. INSIDE DIAMETER FIBER CONDUIT WITH 3-IN. CONCRETE BASE, 3-IN. CONCRETE TOP, 3-IN. CONCRETE SIDES; SEPARATION OF DUCTS, 1 IN., 1½ IN., 2 IN., 2½ IN., 3 IN.

Ducts	Wide High	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
4	2 by 2	5.53	5.98	6.44	6.91	7.40
6	2 by 3	7.18	7.94	8.72	9.53	10.36
8	2 by 4	8.84	9.90	11.00	12.14	13.32
9	3 by 3	9.27	10.50	11.78	13.11	14.49
10	2 by 5	10.49	11.86	13.28	14.76	16.28
12	2 by 6	12.15	13.82	15.56	17.37	19.24
12	3 by 4	11.36	13.06	14.83	16.68	18.61
14	2 by 7	13.80	15.79	17.85	19.98	22.20
15	3 by 5	13.45	15.62	17.89	20.26	22.74
16	4 by 4	13.88	16.21	18.66	21.23	23.91
18	3 by 6	15.54	18.18	20.95	23.84	26.86
20	4 by 5	16.40	19.37	22.49	25.77	29.20
21	3 by 7	17.63	20.74	24.00	27.42	31.00
24	3 by 8	19.72	23.30	27.06	31.00	35.12
24	4 by 6	18.93	22.53	26.32	30.31	34.49

TABLE E.—TRENCH WIDTH AND DEPTH OCCUPIED BY VARIOUS ASSEMBLIES OF FIBER CONDUIT WHEN THE CONCRETE ENVELOPE IS 3 IN. ON TOP, BASE, AND SIDES AND THE SEPARATION OF THE DUCTS IS THE DIMENSION INDICATED

3-in. conduit		When separation between ducts is				
		1 in.	1½ in.	2 in.	2½ in.	3 in.
Ducts		Inches	Inches	Inches	Inches	Inches
2	Wide or = High	14	14.5	15	15.5	16
3		18.5	19.5	20.5	21.5	22.5
4		23	24.5	26	27.5	29
5		27.5	29.5	31.5	33.5	35.5
6		32	34.5	37	39.5	42
7		36.5	39.5	42.5	45.5	48.5
8		41	44.5	48	51.5	55
3½-in. conduit						
2	Wide or = High	15	15.5	16	16.5	17
3		20	21	22	23	24
4		25	26.5	28	29.5	31
5		30	32	34	36	38
6		35	37.5	40	42.5	45
7		40	43	46	49	52
8		45	48.5	52	55	59
4-in. conduit						
2	Wide or = High	16	16.5	17	17.5	18
3		21.5	22.5	23.5	24.5	25.5
4		27	28.5	30	31.5	33
5		32.5	34.5	36.5	38.5	40.5
6		38	40.5	43	45.5	48
7		43.5	46.5	49.5	52.5	55.5
8		49	52.5	56	59.5	63
4½-in. conduit						
2	Wide or = High	17	17.5	18	18.5	19
3		23	24	25	26	27
4		29	30.5	32	33.5	35
5		35	36	39	41	43
6		41	43.5	46	48.5	51
7		47	50	53	56	59
8		53	56.5	59	63.5	67

TABLE F.—THEORETICAL AMOUNTS OF EXCAVATION REQUIRED FOR 100 FT. OF TRENCH

3-in. conduit, 1-in. separation, 100-ft. trench

Trench width	38 in. deep	42½ in. deep	47 in. deep	51½ in. deep	56 in. deep	60½ in. deep	65 in. deep
Inches	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
14	13.73	15.34	16.98	18.59	20.23	21.84	23.48
18.5	18.08	20.19	22.35	24.46	26.63	28.74	30.91
23	22.54	25.17	27.87	30.50	33.20	35.84	38.54
27.5	26.88	30.02	33.24	36.38	39.60	42.74	45.96
32	31.34	35.00	38.76	42.42	45.81	49.84	53.59
'6.5	35.69	39.85	44.13	48.30	52.58	56.74	61.02
41	40.11	44.84	49.65	54.34	59.17	63.83	68.65

3-in. conduit, 2-in. separation, 100-ft. trench

Trench width	39 in. deep	44½ in. deep	50 in. deep	55½ in. deep	61 in. deep	66½ in. deep	72 in. deep
Inches	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
15	15.04	17.17	19.30	21.38	23.40	25.64	27.77
20.5	20.58	23.12	26.91	29.26	32.17	35.09	38.00
26	26.12	29.81	34.15	37.13	40.82	44.52	48.22
31.5	31.53	36.00	41.24	44.83	49.29	53.72	58.22
37	37.07	42.32	48.48	52.70	57.94	63.16	68.44
42.5	42.61	48.64	55.72	50.57	66.60	72.63	74.96
48	48.14	54.96	62.96	68.44	75.25	82.07	88.88

3-in. conduit, 3-in. separation, 100-ft. trench

Trench width	40 in. deep	46½ in. deep	53 in. deep	59½ in. deep	66 in. deep	72½ in. deep	79 in. deep
Inches	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
16	16.40	14.98	21.77	24.43	27.09	29.75	32.04
22.5	23.06	26.80	30.61	34.35	38.09	41.83	45.57
29	29.47	34.67	39.61	44.45	49.29	54.13	58.97
35.5	36.13	42.42	48.49	54.37	60.29	66.21	72.13
42	43.16	50.16	57.29	64.29	71.29	78.29	85.29
48.5	49.82	57.98	66.13	74.21	82.29	90.37	98.45
55	56.48	65.64	74.97	84.13	93.29	102.45	111.62

TABLE G.—THEORETICAL AMOUNTS OF EXCAVATION REQUIRED FOR 100 FT. OF TRENCH

3½-in. conduit, 1-in. separation, 100-ft. trench

Trench width	39 in. deep	44 in. deep	49 in. deep	54 in. deep	59 in. deep	64 in. deep	69 in. deep
Inches	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
15	15.04	16.99	18.88	20.83	22.77	24.67	26.62
20	20.10	22.69	25.23	27.83	30.43	32.96	35.56
25	25.77	24.57	31.43	34.66	38.12	41.06	44.29
30	30.09	33.98	37.77	41.29	45.55	49.35	53.24
35	25.11	37.82	41.16	48.66	53.20	57.64	62.92
40	40.08	45.62	50.32	55.50	60.68	65.73	70.97
45	48.84	50.97	56.66	62.50	68.33	74.02	79.86

3½-in. conduit, 2-in. separation, 100-ft. trench

Trench width	40 in. deep	46 in. deep	52 in. deep	58 in. deep	64 in. deep	70 in. deep	76 in. deep
Inches	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
16	16.43	18.86	21.32	23.79	26.25	28.71	31.18
22	22.57	25.95	29.34	32.73	36.12	39.51	42.90
28	28.73	33.05	37.36	41.68	45.92	50.31	54.62
34	34.90	40.10	45.38	50.62	55.86	61.10	66.34
40	41.07	47.23	53.40	59.57	65.73	71.90	78.07
46	47.23	54.32	61.42	68.51	75.60	82.32	89.79
52	53.40	61.42	69.44	77.45	85.47	93.49	101.51

3½-in. conduit, 3-in. separation, 100-ft. trench

Trench width	41 in. deep	48 in. deep	55 in. deep	62 in. deep	69 in. deep	76 in. deep	83 in. deep
Inches	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
17	17.98	21.03	24.08	27.19	30.24	33.29	36.39
24	25.33	29.62	33.92	38.29	42.59	46.88	51.25
31	32.68	38.22	43.76	49.40	54.94	60.48	66.12
38	40.15	46.96	53.77	60.69	67.50	74.32	81.24
45	47.12	55.55	63.61	71.80	79.86	87.90	96.11
52	54.84	64.14	73.44	82.91	92.21	101.51	110.97
59	62.46	72.88	83.45	94.39	104.77	115.34	126.09

TABLE H.—THEORETICAL AMOUNTS OF EXCAVATION REQUIRED FOR 100 FT. OF TRENCH

4-in. conduit, 1-in. separation, 100-ft. trench

Trench width	40 in. deep	45.5 in. deep	51 in. deep	56.5 in. deep	62 in. deep	67.5 in. deep	73 in. deep
Inches	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
16	16.45	18.72	20.98	23.24	25.51	27.77	30.04
21.5	22.11	25.18	28.20	31.23	34.28	37.30	40.36
27	27.77	31.60	35.41	39.25	43.05	46.85	50.65
32.5	33.41	38.03	42.62	47.26	51.85	56.42	61.01
38	39.09	44.46	49.81	55.38	60.59	66.00	71.41
43.5	44.75	50.90	57.05	63.27	69.38	75.51	81.75
49	50.40	57.34	64.27	71.35	78.20	85.06	92.15

4-in. conduit, 2-in. separation, 100-ft. trench

Trench width	41 in. deep	47.5 in. deep	54 in. deep	60.5 in. deep	67 in. deep	73.5 in. deep	80 in. deep
Inches	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
17	17.92	20.76	23.61	26.45	29.29	32.14	34.97
23.5	24.78	28.68	32.62	36.55	40.48	44.46	48.40
30	31.62	36.82	41.68	46.65	51.67	56.65	61.65
36.5	38.52	44.55	50.67	56.78	62.92	69.07	75.10
43	45.40	52.50	59.75	66.98	74.08	81.26	88.50
49.5	52.18	60.48	68.78	77.01	85.40	93.58	101.98
56	59.01	68.45	77.75	87.08	96.50	105.98	115.05

4-in. conduit, 3-in. separation, 100-ft. trench

Trench width	42 in. deep	49.5 in. deep	57 in. deep	64.5 in. deep	72 in. deep	79.5 in. deep	87 in. deep
Inches	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
18	19.44	22.91	26.35	29.85	33.33	36.80	40.25
25.5	27.54	32.46	37.37	42.29	47.22	52.11	57.03
33	35.64	42.00	48.37	54.70	61.11	67.44	73.81
40.5	43.74	51.55	59.37	67.18	75.00	82.77	90.59
48	51.85	61.11	70.37	79.57	88.88	98.14	107.40
55.5	59.91	70.62	84.18	92.03	102.77	113.25	140.96
63	68.03	80.18	92.33	104.44	116.66	128.55	

TABLE I.—THEORETICAL AMOUNTS OF EXCAVATION REQUIRED FOR 100 FT. OF TRENCH

4½-in. conduit, 1-in. separation, 100-ft. trench

Trench width	41 in. deep	47 in. deep	53 in. deep	59 in. deep	65 in. deep	71 in. deep	76 in. deep
Inches	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
17	17.80	20.47	23.03	25.69	28.25	30.91	33.05
23	24.12	27.87	31.35	34.98	38.47	42.09	45.01
29	30.43	34.98	39.36	43.95	48.65	52.84	56.[illegible]0
35	36.87	42.39	47.65	53.57	58.87	64.02	68.45
41	43.06	49.50	51.69	62.11	68.32	74.76	83.64
47	49.50	56.91	64.02	71.39	78.54	85.94	91.90
53	55.69	64.02	72.03	80.36	88.36	96.65	103.39

4½-in. conduit, 2-in. separation, 100-ft. trench

Trench width	42 in. deep	49 in. deep	56 in. deep	63 in. deep	60 in. deep	77 in. deep	83 in. deep
Inches	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
18	19.44	22.68	25.92	29.18	32.40	34.64	38.44
25	26.96	31.43	35.97	40.44	44.91	49.38	53.30
32	34.61	42.76	46.18	51.91	57.65	63.15	67.69
39	42.13	49.11	56.21	63.19	70.17	77.15	83.29
46	49.64	57.87	66.24	74.55	83.29	90.92	98.16
53	57.29	66.79	76.27	85.94	95.22	104.69	113.58
59	53.77	74.34	83.98	95.66	102.53	116.98	126.09

4½-in. conduit, 3-in. separation, 100-ft. trench

Trench width	43 in. deep	51 in. deep	59 in. deep	67 in. deep	75 in. deep	83 in. deep	91 in. deep
Inches	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards	Cubic yards
19	21.01	24.92	28.82	32.74	36.64	40.55	44.46
27	29.85	35.41	40.96	46.51	52.07	57.62	63.18
35	38.70	45.88	53.11	60.29	67.48	74.70	81.85
43	47.55	56.37	65.22	74.07	82.92	91.74	100.62
51	56.37	66.88	77.11	87.88	98.37	108.85	119.33
59	65.22	77.37	89.52	101.64	113.77	125.92	138.07
67	74.09	87.85	101.69	115.44	127.44	143.02	156.81

COMPARISON OF LABOR COSTS BETWEEN FIBER AND TILE DUCT

The following are two sections of underground conduit constructions consisting of 12 single-tile or clay duct and 12 fiber duct installed at different times but over the same route. It will be noted in comparing the two analyses of cost that the removal of paving in connection with the fiber conduit was lower in cost due to the use of a portable air compressor and pneumatic paving breakers, while on the other hand, the paving in connection with the clay duct was removed by hand.

Excavation Cost.—This was higher in connection with the fiber duct due to the formation and depth of the trench and to the necessity of crossing another duct line while the clay duct line was laid 2 ft. wide and 6 ft. high.

Laying Conduit.—The reason for the low cost of laying fiber duct is due to the lightness of the material, the unit length, and laying by the built-up method.

Concreting.—The low cost of concreting the fiber duct is due to the method used. As will be noted with the clay duct, the concrete was poured one layer at a time and 12 hr. was allowed for setting of each layer.

Table of Comparison

	Tile	Fiber	Difference
Removing paving	$0.086	$0.0211	$0.065
Excavating	1.090	1.1388	0.048
Laying conduit	0.381	0.1112	0.270
Mixing and pouring concrete	0.465	0.2209	0.245
Backfilling	0.164	0.2078	0.043
Removing surplus dirt	0.252	0.1612	0.091
Hauling material	0.491	0.4092	0.082
Total	$2.929	$2.2702	$0.844

The actual amount of excavating in cubic yards and the cost is as follows:

Fiber .... 1,650 cu. yd. at $1.81
Tile .... 1,450 cu. yd. at 2.00

The reason the cost per cubic yard on the fibre was less is because the trench was wider and easier to work in. The actual amount of concrete used was:

Fiber .... 527 cu. yd. at $1.10
Tile .... 455 cu. yd. at 2.72

Backfilling Cost.—This was high on the fiber duct due to the depth and width of the trench.

Hauling Surplus Dirt.—Was high in cost in connection with the clay duct due to hauling while 50 per cent of the dirt in connection with the fiber duct was spread over the street.

Hauling Material.—The cost of this was high on clay duct due to the weight of the material, the unit length, and the small loads necessary on account of weight. At least two thirds more of the fiber can be hauled to a load.

ANALYSIS AND COST OF LABOR OF A TWELVE-WAY 4½-IN. SINGLE-TILE DUCT UNDERGROUND CONDUIT

Removal of Pavement.—It was necessary to remove by hand tools 155 sq. yd. of 5-in. brick block pavement constructed with a 2-in. concrete base.

Excavating.—The soil was clay and sand mixed and had to be braced the full length of trench. The trench crossed under a double railroad track and at this point the trench was excavated so there would be a minimum of 48 in. between the top of duct structure and the base of the rails. The balance of the trench was excavated so that there would be a minimum of 24 in. between the top of the duct structure and the street level.

Laying Conduit.—The conduit was laid by the tier-by-tier method two wide and six high. The joints were made tight by using muslin 3 in. wide, the conduit and muslin being painted with P & B paint or No. 2 compound (see construction of single-tile duct, pp. 44 and 45).

Concreting.—The concrete mixture was 1:3:6 of portland cement, sand, and ½-in. rock. The mixing was done with a one-sack mixer. The concrete was wheeled from the mixer to the trench for a distance not over 100 ft.

Surplus Earth.—Was hauled approximately ¼ mile to a dump by motor trucks.

Hauling Material.—Motor trucks were used for hauling material to the job for a distance of ¼ mile.

Minimum depth of the trench was 5 ft. 8 in.; maximum depth 11 ft. 8 in.; average depth 8 ft. 4 in.; average width 20 in., with the exception of one section which was 33 in. wide.

Duct feet..........	31,920
Trench feet........	2,660
Conduit used......	Twelve 4½-in. square bore tile duct
Concrete mixture..	1:3:6, portland cement, sand, and ½-in. rock
Concrete envelope..	3-in. top, 3-in. sides, 3-in. base, and 1½-in. separation
Common labor.....	9 hr. per day at 45 to 50 cts. per hour

MAN-HOURS

Item	Total hours	Per trench foot	Per duct foot
Removing paving	458	0.172	0.014
Excavating	6,459	2.428	0.202
Laying conduit	2,022	0.760	0.063
Mixing and pouring concrete	2,634	0.990	0.083
Backfilling	941	0.354	0.030
Loading and removing surplus dirt	920	0.346	0.029
Hauling material	1,668	0.627	0.052
Total	15,102	5.677	0.473

LABOR COSTS

Item	Total	Per trench foot	Per duct foot
Removing paving	$ 228.12	$0.086	$0.007
Excavating	2,900.66	1.090	0.091
Laying conduit	1,013.31	0.381	0.032
Mixing and pouring concrete	1,236.12	0.465	0.039
Backfilling	434.89	0.164	0.014
Loading and removing surplus dirt	671.23	0.252	0.021
Hauling material	1,306.30	0.491	0.041
Total	$7,790.63	$2.929	$0.245

ANALYSIS AND COST OF LABOR OF A TWELVE-WAY UNDERGROUND CONDUIT CONSISTING OF A 4½-IN. FIBER DUCT

Removal of Pavement.—It was necessary to remove 157 sq. yd. of pavement constructed of 9-in. concrete base and 5-in. brick blocks. This was removed with a portable air compressor and pneumatic paving breakers.

Excavation.—The soil was a clay and sand mixture which required bracing the full length of the trench. The conduit crossed under double railroad tracks at this point. The trench was excavated so there would be a minimum of 48 in. between the top of the duct structure and the rail base. The balance of the trench was excavated so that there would be a minimum of 24 in. between the top of the duct structure and the street level.

Laying Conduit.—The conduit consists of 4½-in. fiber Harrington joint and the construction was accomplished by the built-up method using concrete separators 3 in. square. The formation was 3 ft. wide and 4 ft. high.

Concreting.—The concrete mixture consisted of 1:3:6, portland cement, sand, and ½-in. rock. The mixing was accomplished in a one-sack mixer and concrete was poured directly from the mixer to the trench.

Surplus Earth.—Approximately 50 per cent of the surplus earth was hauled ¼ mile to a dump with a motor truck and the balance spread over low places in the street which was not paved or graded.

Hauling Material.—Motor trucks were used for hauling material to the place of construction. The minimum depth of the trench was 5 ft.; maximum depth 13 ft. 2 in.; average depth 7 ft. 4 in.; average width 27 in. with the exception of two sections which were 36 in. wide.

Duct feet	31,470
Trench feet	2,622.5
Conduit used	twelve 4½-in. fiber Orangeburg
Concrete mixture	¾:2:5, cement, sand and chat
Concrete envelope	3-in. bottom, 3-in. sides, 3-in. separation, 3-in. top
Common labor	9 hr. per day at 40 to 45 cts. per hour

MAN-HOURS

Item	Total hours	Per trench foot	Per duct foot
Removing paving	127.5	0.0487	0.0040
Excavating (clay)	7,370	2.8103	0.2342
Laying conduit	667	0.2543	0.0212
Mixing and pouring concrete	1,393.5	0.5314	0.0443
Backfilling	1,308.5	0.4989	0.0416
Hauling material	1,443	0.5502	0.0458
Removing surplus dirt	516	0.1968	0.0164
Miscellaneous labor	594	0.2265	0.0189
Total	13,419.5	5.1171	0.4264

LABOR COSTS

Item	Totals	Per trench foot	Per duct foot
Removing paving	$ 55.30	$0.0211	$0.0018
Excavating (clay)	2,986.47	1.1388	0.0949
Laying conduit	291.55	0.1112	0.0093
Mixing and pouring concrete	579.27	0.2209	0.0184
Backfilling	545.09	0.2078	0.0173
Hauling material	1,073.09	0.4092	0.0341
Removing surplus dirt	422.86	0.1612	0.0134
Miscellaneous labor	258.70	0.0986	0.0082
Total	$6,212.33	$2.3688	$0.1974

CHAPTER VI

UNDERGROUND TRANSMISSION AND DISTRIBUTION

The problem of designing the getaway of conduit and cables leaving a power plant or entering a substation requires a great deal of study and planning for immediate and future feeders and circuits. It is necessary to consider the separation of the primary feeders transmitting power from the power plant to the various substations. Parallel feeders should be arranged to leave the power plant from different bus sections of the power house. These cables to be separated in the separate ducts to manholes or group of manholes, to avoid having two cables feeding the same substation in the same duct run and manhole.

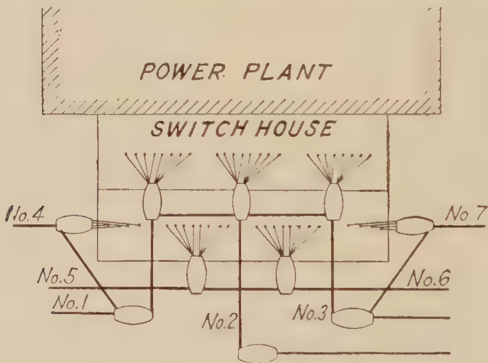


Fig. 106.—Plan of power house getaway.

The plans of the power plant or substation should take this into consideration. It may be advisable to build manholes within the station to take care of the segregation of cables of this class. This depends a great deal upon the local conditions. For example, the feeder may pass from the bus compartment directly to the main underground conduit outside of the building or it may go to a manhole within the plant and then to the underground conduit in the street. The latter system is more flexible and makes it possible to get a number of combinations so that feeder locations are interchangeable. This feature is sometimes very

useful as a system grows. It may, for instance, be found that a certain feeder would give better operations on another section of the bus. Figure 106 shows a plan for conduit in a power house with the above idea worked out. The switch house is divided in two rooms by a brick wall, with a bus compartment in each room. Each conduit run is numbered to simplify the keeping of records. If a feeder is installed in the conduit run No. 1, it can be connected to the first section of the bus or to second or third section through interconnecting duct runs between the manholes. The same applies to runs No. 2 and No. 3. As 4 and 7 are intended to be used in the switch room No. 2, only an interconnecting duct run is provided so that if desired a feeder

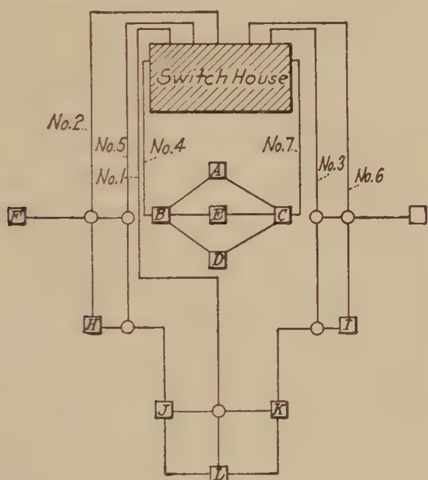


FIG. 107.—Diagram showing the seven duct runs leaving switch house and going to various substations.

can be connected from runs 4 or 7 to the first or the third section of the bus in run No. 1. This makes a flexible layout and it is possible to isolate feeders so that no more than one or two feeders going to a station will be in the same duct run or manhole.

Figure 107 is a diagram showing the seven duct runs leaving the switch house and going to the various substations, which are indicated by a square and lettering. The circles indicate the main intersecting manholes. The A, B, C, D, and E substations are located in what might be the congested district. The others are in the outlying districts. These duct runs should be

constructed in different streets or at least separated according to local conditions. The diagram given covers 125 sq. miles or more.

Distribution.—There are a great many systems of underground distribution in use today. We have passed from the old Edison tube system to lead-covered cables installed in conduit, and manhole junction boxes are provided to care for distribution at feeding points and for fusing d.-c. distribution and a.-c. distribution in which underground transformer and a.-c. network are used.

Fig. 108.—Example of poor cable installations.

The underground Edison cable system is an expensive system. In years gone by, however, it was considered the best, and while much money was invested in it, it seemed wise to build on as the load increased. In spite of the high cost many of these systems have been remodeled from time to time and better and more economical distribution was made possible. This is accomplished by a thorough study of loading conditions and proper location of substations in relation to the load. A very vital point in all underground cable construction is the proper placing or racking of cables in the manholes or substations to care for the proper bending without injuring the insulation. Short bends are responsible for many underground failures. Short bends near

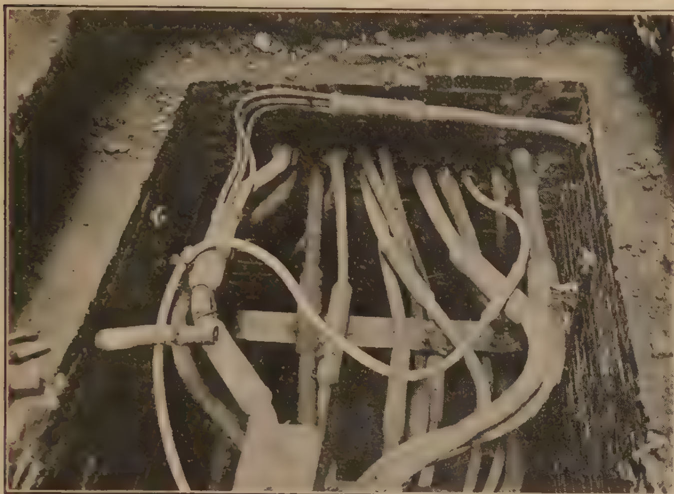


Fig. 109.—Cables have been improperly racked. The bends in cable are too short.

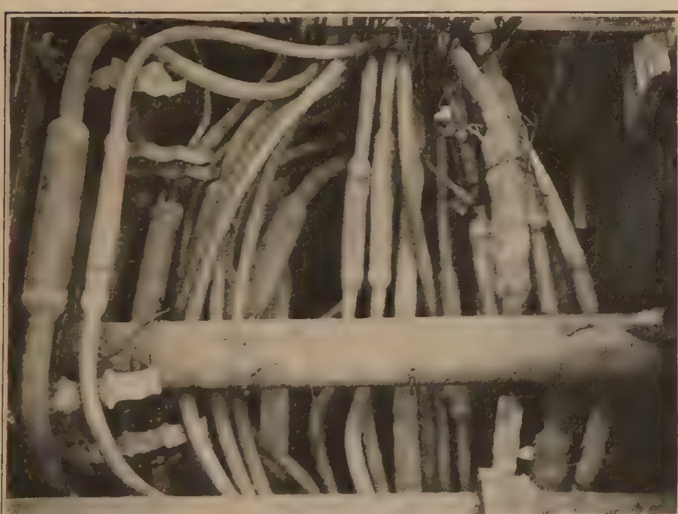


Fig. 110.—Many repairs become necessary. Very poor duct selections cause crossed cables.

the edge of the duct cause chafing of the lead which finally cuts through to the insulation, allowing moisture to enter and causing short-circuits. As the cable is loaded it is heated, and as load goes off, the cable cools and the result is a creeping back and forth of the cable. Various appliances to prevent this have been tried, but they seem to be only temporary help.

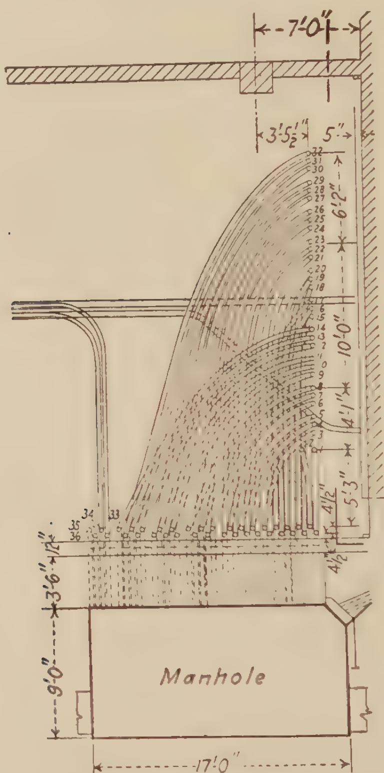


FIG. 111.—Substation on getaway for d.-c. cables

The writer has noted some manholes where cables were run through without racking, and, in many cases where they were racked, the bending was so short that the insulation was ruined at the first installation and many failures resulted, making successive repairs necessary until finally it was impossible to enter the manholes without prying the cables apart. Figures 108, 109, and 110 show such conditions. These conditions sometimes arise through lack of funds and because not enough interest is taken in the underground plant.

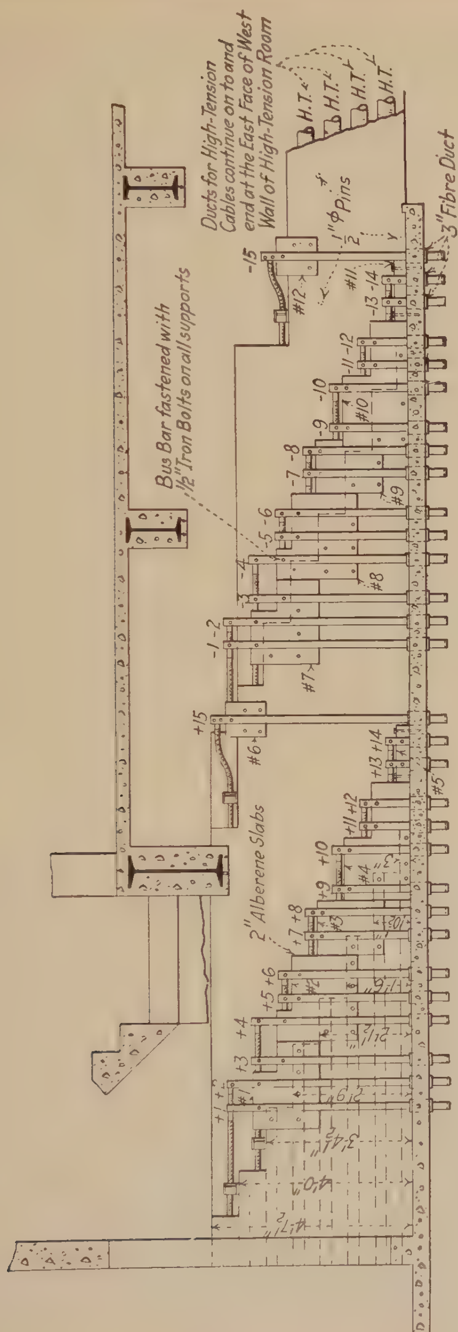


FIG. 112.—Substation getaway for d.-c. cables.

It is important that the proper getaway from the substation is provided for cable. Figure 111 is an illustration of how this can be taken care of. The point in mind is to protect the cables as far as possible inside the substation and as close to the switchboard as possible. It is therefore necessary to plan the conduit construction work in advance so that these important parts can be taken care of. This plan shows a large manhole outside of a substation. Conduits are constructed through the station wall and a double row of racks provided on the wall. Fiber conduit is constructed in the floor of the substation from the wall to the switchboard. The ducts are grouped so that positive and negative cables go into the manhole in pairs, while the switch-

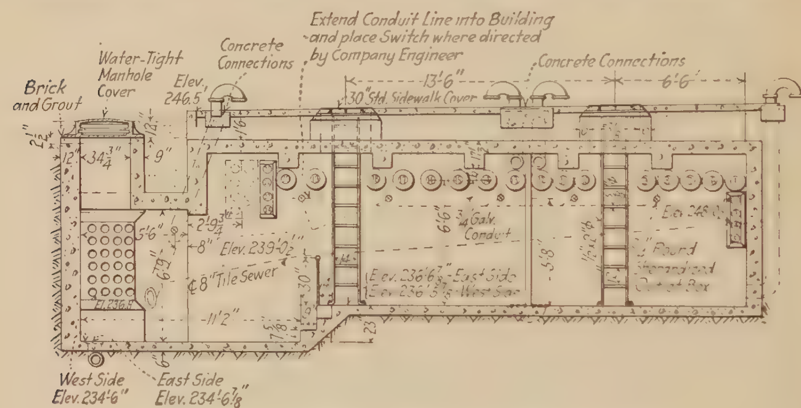


FIG. 113.—Distribution manhole for 4500 volt cables.

board is so arranged that the left-hand half is positive and the right-hand half negative. With this plan it is necessary to assign ducts in the street conduit for every duct in the station.

Figure 112 is another layout for d.-c. distribution. Fiber conduit was built alongside the building wall at an elevation above the switchboard and a reinforced concrete shelf with reinforcing was attached to the main building wall. The advantage of this plan is the simplicity of the elimination of bending cables and of training cables down behind the switchboard. It will be noted that four ducts next to the building wall are used for transmission cables. Three-inch concrete separation was used on this construction.

Figure 113 is a distribution manhole for 4,550-volt, four-conductor distribution cable. While this is a large manhole, there

Fig. 114.—Distribution manhole under construction. Ducts project out into the manhole and continue along the wall incased in concrete. Stepping off the various ducts to correspond with the duct selected to leave the substations for cable going to a specified location.

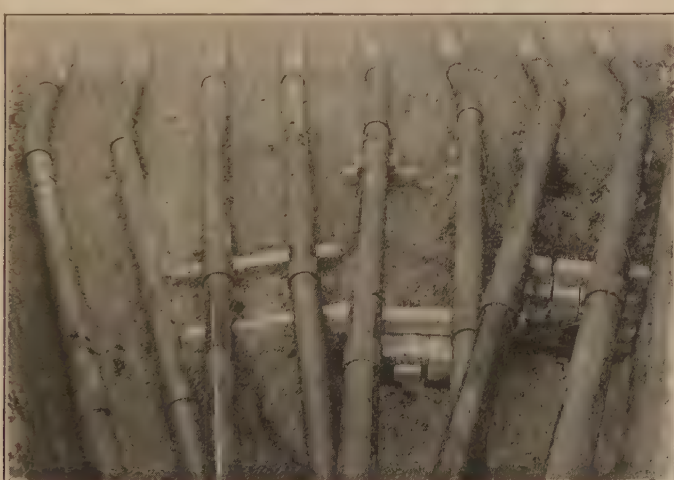


Fig. 115.—Another plan of getaway from substation.

are only a few feet of cable exposed in the manhole. There are 16 ducts coming out of the station and 4 ducts to the left and right for future use. The eight ducts shown in dotted lines are the transmission ducts which pass through this manhole into the station from a transmission manhole. The 24 ducts on the left are for circuits going north and another conduit going south out of the manhole to the right of the illustration. It will be noted that a concrete wall is constructed about the center of the manhole for fire protection. Two manhole openings are provided with iron ladders. Every compartment is ventilated by an 8-in. pipe, one near the bottom of the manhole and one near the top.

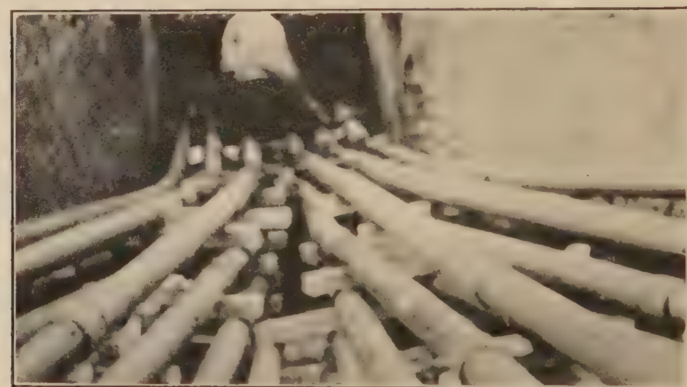


FIG. 116.—Showing method used for transposing ducts. The conduit is built up complete before the concrete is poured.

Lighting is also provided in this manhole. The conduit which goes out of the manhole on the right is brought into the manhole along the wall and each duct which corresponds to the one going into the station is dropped off and the whole bank concreted to the manhole wall. This manhole is constructed partly under the sidewalk base and the west side of the manhole wall projects outside the curb line so that the conduit could be constructed in the street.

Figure 114 shows the manhole with concrete walls completed and showing the ducts at the south end of the manhole. The ducts project into the manhole and continue along the wall in the concrete, stepping off to correspond with the corresponding ducts going into the station.

Figure 115 shows another plan of a getaway from a substation. All the ducts go through the station wall and turn up on the

other side of the wall with a 90-deg. bend. The fibre ducts are built in the wall and the potheads are mounted there on the cables. The ducts leave the station wall and go to two manholes on the opposite side of the street, one manhole taking care of circuits going north and the other going south. While the ducts leave the station on one plane, they enter the manhole 3 ft. wide and 6 ft. high.

Figure 116 shows the method used for transposing the ducts. The conduit is built up complete and then the concrete is poured.

JUNCTION BOXES AND TERMINAL POLES IN CONNECTION WITH UNDERGROUND DISTRIBUTION

To give continuous service without interruption is the aim of every electric-service company but a great deal depends upon the design and installation of conduit manholes, junction boxes,

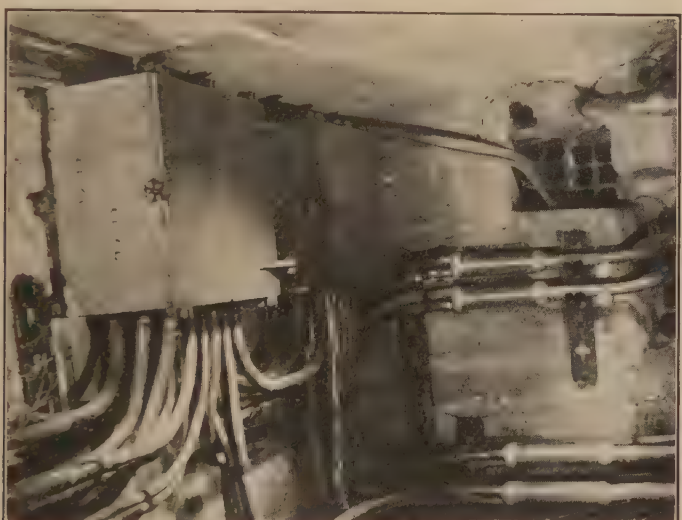


FIG. 117.—Two six position junction boxes.

cable, etc. A very important part of underground construction is the installation and splicing of cables. A few examples of junction-box manholes are shown in Figs. 117, 118, 119, and 120. Figure 117 is a manhole with two six-position junction boxes for an underground Edison system. The proper care in bending and training cables around a manhole is very important to prevent crosses as far as possible and to leave the cable accessible for

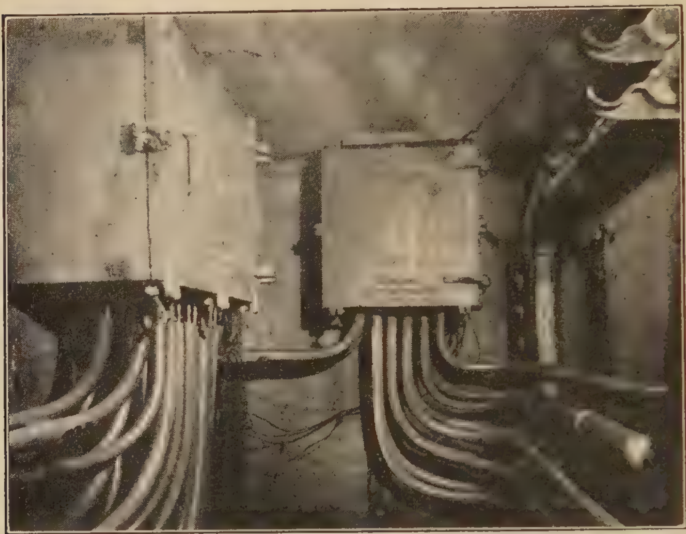


FIG. 118.—A ten and six position junction box.

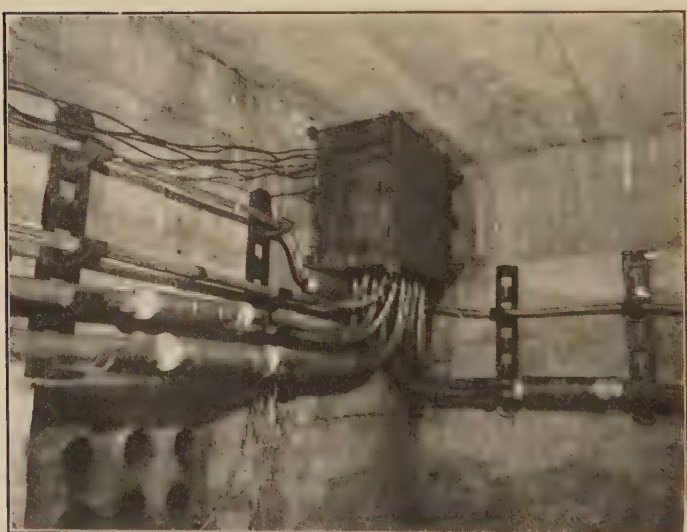


FIG. 119.—A six position junction box.

inspection and repairs. While it is not always possible to lay out a system for very many years in advance, it is sometimes necessary from time to time to enlarge the system. This makes it necessary to change the feeding point of some of these circuits and makes it necessary to enlarge some of the manholes to take care of proper racking of cables and to make room for additional junction boxes and cables. In this picture will be noted 1,500,000-cir. mils and 1,000,000-cu. mils lead-covered cable used to feed the buses in the boxes, both boxes being tied together. The

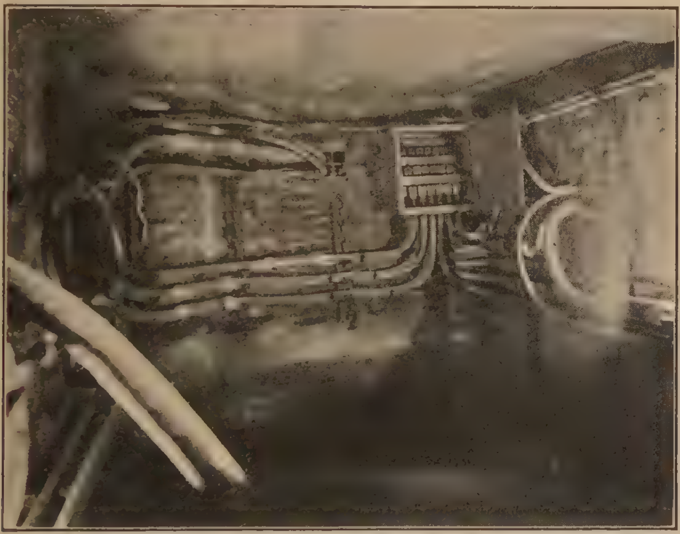


Fig. 120.—A six position junction box open to show busses and cable connections.

three-conductor cables are mains leaving the boxes and taped at intervals for service to customers. The small cable in the picture is the pressure wire cable which enables the load dispatcher to check the pressure at the various points on the system. Figure 118 shows a six- and ten-position junction box. Figure 119 shows a six-position box in place. This manhole has been enlarged to take care of additional load and it will be noted that this box is mounted near the ceiling in the manhole. This allows the racking of a low-voltage cable at the highest elevation leaving room for new cables to be installed in new ducts as shown. (The wires leading out of the box near the top are temporary lighting wires.) The lower part of this manhole can be

used for cables passing through manholes or for transmission cables, thus keeping them below the d.-c. cables and protecting them from excessive heat. Figure 120 is another manhole which has been enlarged to allow better racking and to make room for new cable. Only one junction box can be seen. The door is open to show the lug and fuse connections. The junction boxes are painted white or with aluminum paint. Experience

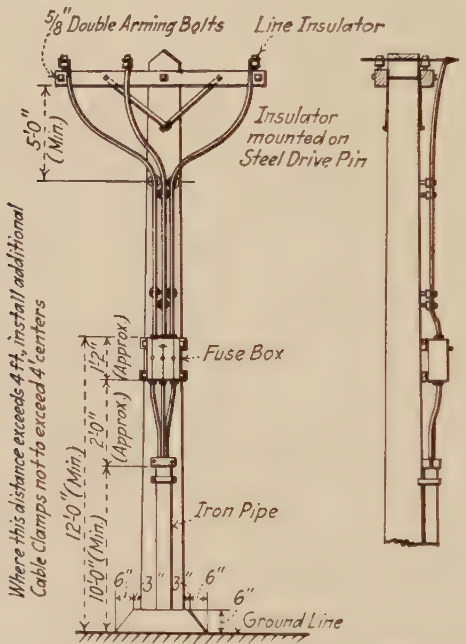


FIG. 121.—Fuse box used in connection with d.-c. system from underground to overhead.

has shown that the light-colored paint helps in lighting the manhole. Figure 121 is a fuse box which is used in connection with d.-c. system from underground to overhead connections. These boxes are cast-iron lined with transite board, micarta blocks being used to mount the lugs and fuses. Link fuses are used and single-conductor, lead-covered cable is used from the underground mains to the box, and three lengths of the same are used in the top of the box. The connection between the lead-covered cable and the box is made water-tight by a clamp. The overhead wire is spliced to the short pieces of lead-covered cable and made tight with taping and compound, thus preventing water from

leaking into the box on the overhead wire. Fiber conduit is used from the manhole to the pole with fiber bends, using a 36-in. radius bend at the pole and iron pipe up the pole for 10 ft. Concrete is poured around the base of the pole to prevent trucks from damaging the pipe and cable.

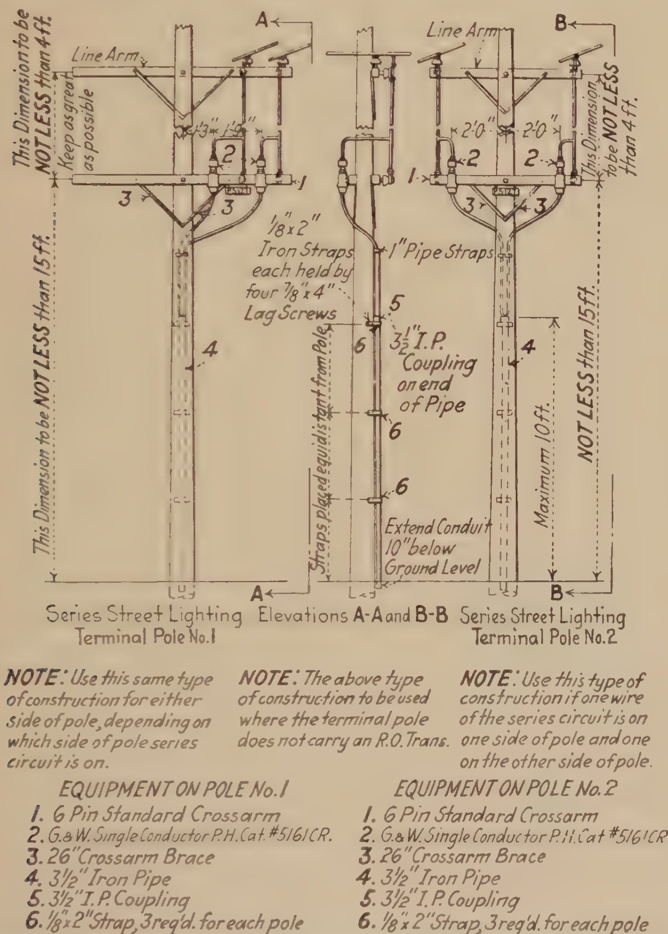


FIG. 122.—Terminal poles for connections to underground cable for series street lighting.

Terminal Poles.—Where it is necessary to connect underground cables to overhead lines for transmission or distribution, a terminal pole is used to take care of the cable, potheads, lightning arresters, fuses, etc. A location is selected which will be con-

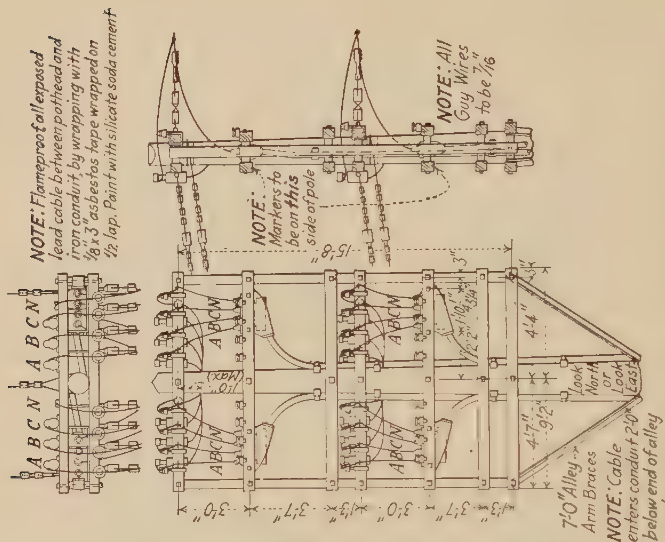


FIG. 124.—Terminal pole for four cables.

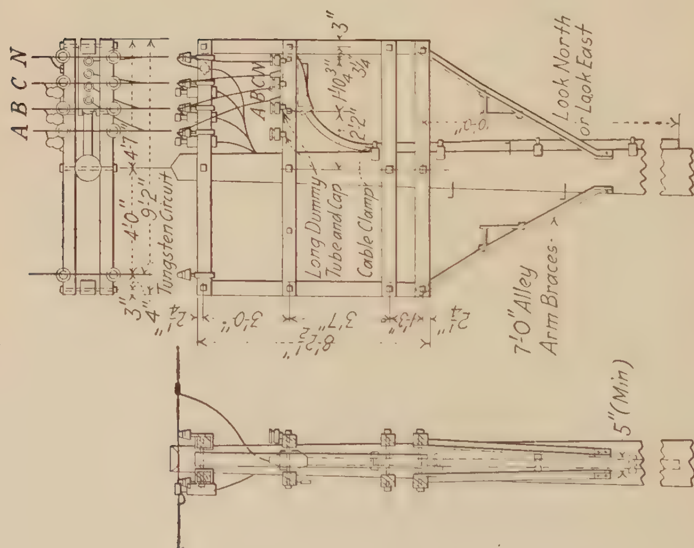


FIG. 123.—Terminal pole for two cables.

venient to the overhead construction and the underground manholes. A pole of first-class condition of good-sized butt, with top straight and smooth should be selected and it should be properly guyed.

Figure 122 shows series, street-lighting terminal poles. The underground cable in this instance is lead-covered cable with triple-braid which is merely buried in the ground without conduit. The cable is brought up the pole through an iron pipe about 10 ft. long and the pipe is supported by iron clamps on the pole, one clamp at the top of the pipe placed under a coupling to support the weight of pipe. Single-conductor disconnecting potheads are used. The cable is fastened to the pole with pipe straps. Figures 123 and 124 show a two-position and four-position terminal pole for 4,500 volts distribution. Here, the underground cables are installed in fiber duct from the manhole to the terminal pole and in iron pipe up the pole about 15 ft. The pipe is clamped to the pole with iron straps. The four-conductor cable is fastened to the pole with a special maple-wood clamp boiled in oil. A four-conductor *Y*-type disconnecting pothead is used. The lead cable is protected from flame or arc by wrapping with asbestos soaked in silicate of soda. A special maple-wood clamp is put on the cable at the top of the pipe to prevent the cable from slipping and to cover the end of the pipe. Where possible no more than two cables should be installed on one terminal pole. Four cables make a rather congested terminal for linemen and trouble men. Figure 128 shows the congested condition of a four-position pole. A good plan is to run two cables to the pole nearest to the manhole and then two more cables can be run to the next pole on the line.

Fig. 125.—Terminal pole for two circuits 13,200 volts.

Figure 125 shows a two-position terminal pole for 13,200-volt transmission using three-conductor cable up the pole to about 5 ft. from the first cross arm, where a three-way splice is made and single conductors are brought up to cross arms and single-

conductor potheads are used. The platform is used for mounting lightning arresters and other equipment.

Figure 126 shows a steel structure crossing terminal. On this terminal fiber conduit is run to the terminal as on the other wooden poles and this illustration shows a three-conductor, *Y*-type, 15,000-volt pothead. Figure 127 is an elevation of the

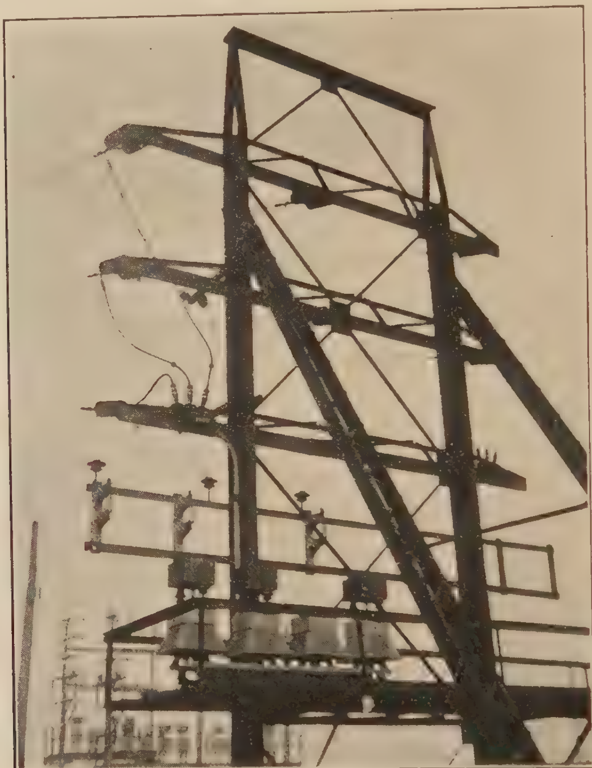


FIG. 126.—Strain tower used as terminal for underground cable to overhead river crossing.

conduit construction used between manholes and a terminal pole. Fiber conduit is installed from the manhole to the terminal pole using at least 3-in. separation of concrete between ducts and a 36-in. radius 90-deg. fiber bend, and an iron pipe up the pole. The joint between the iron pipe and fiber is made with standard iron-pipe coupling with the threads turned out to take the fiber duct. This joint is made tight with P & B paint or white lead and the concrete is poured to a height above this point.

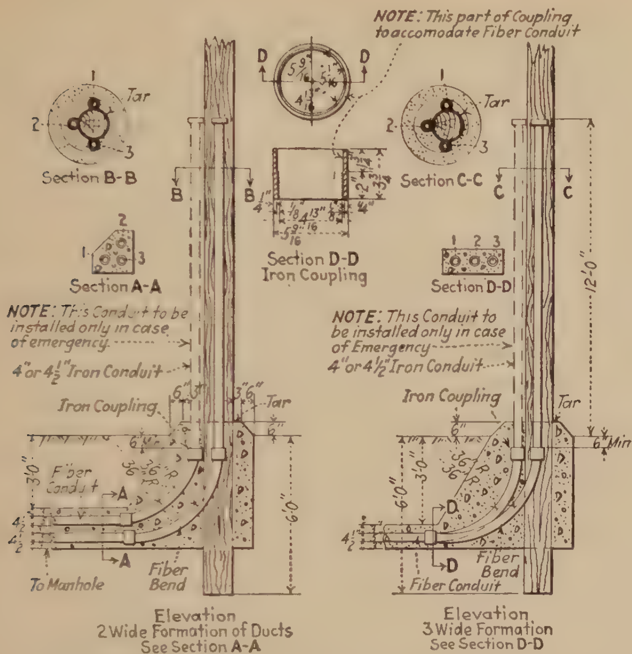


Fig. 127.—Method of making connection between fiber and iron conduit.

Fig. 128.—A four position terminal pole.

The pipe is fastened to the pole with iron clamps. The cable is fastened with wooden clamps as explained. The depth of the pole hole is 6 ft.; the depth from the street surface to the duct structure is 3 ft. A 4½-in. conduit is used for three-conductor, 400,000-cir. mil, 13,200-volt cable. A 4-in. pipe is used for four-conductor, or 3/0- 300,000-cir. mil, or 3/0-13,200-volt cable. Concrete is poured all around the conduit and pole as shown. Before pouring the concrete an old auto-tire inner tube is wrapped around the pole at the point where the concrete stops leaving the tube sticking out of the concrete about ½ in. The same is done with the conduit. Iron-wire reinforcing of circular shape is used in the concrete around the pole. After the concrete is set, the rubber tube is pulled out and hot tar or other compound is poured in the space provided by the tube. This is done to keep out moisture and protect the pole. The joint should be inspected from time to time and kept sealed so that water cannot enter.

CHAPTER VII

UNDERGROUND CABLE INSTALLATION

As the power supply of the electric-service companies to the substation lines and customer substations is dependent upon the underground cables, everything must be done to prevent their failure. Careless handling of cables and poor jointing cause many failures. Therefore, a set of instructions should be in the hands of men installing cable. The instructions should be followed in order to prevent as far as possible failures due to these causes.

Cable Tests.—The cable test on each length should be made at the factory before the cable is shipped. A record of the test should be inspected by a representative of the purchaser. Samples taken from lengths designated by the purchaser should be sent to a testing laboratory for verification of the tests or such additional investigation and tests as the purchaser may desire. All reels should be marked with the size of the cable, number of conductors, kind of insulation, size of insulation, and whether the conductors are round or otherwise. Each section should be numbered between manholes, using manhole numbers and location for delivery, giving street location for unloading close to the manhole where cable will be pulled in. All of this information should be previously furnished the manufacturer with cutting lengths, and the manufacturer should mail to the purchaser a shipping memorandum of each carload, giving reel numbers, etc., so that when a car arrives the purchaser knows in advance what it contains and is able to handle his organization at a minimum cost. The cutting lengths should be given the manufacturer from a given point, that is, if the cable is to be installed from a power house to a substation, the cutting lengths should begin at the power house and continue through to the substation. The manufacturer must ship cable in sequence as listed, so that when the cable is loaded in cars there will not be, for instance, four reels to unload at the power house, two reels about half-way to the substation, and a few reels scattered along toward

the substation. When installing a feeder several miles long, if the cable is shipped as mentioned, it will incur a large expense to the purchaser. In this case it would be necessary for the pulling crew to move long distances for every pull whereas if the cable were shipped in sequence the pulling crew could begin at one end and work toward the completion of the feeder. This would allow splicing crews to follow along after the pulling crew, while if cable is shipped by the skip method many thousands of feet might be pulled in and there would still be no jointing ready. Cable should be pulled in as soon as possible to get the reels off the street. This is especially important in congested districts.

FIG. 129.—A five ton truck unloading a car of cable.

Handling.—Cable is received from the factory in cars loaded by the manufacturers. It is supposed to be correctly loaded and the car carefully handled by the railroads but experience has shown that such is not always the case. Note, therefore, whether the reels have shifted about the cars and become damaged. A detailed report of any damage should be made at once. The cable reels should not be removed from the car until a representative of the railroad company has inspected it. A detailed report should be made also to the manufacturer shipping the cable, giving reel and section numbers. A very close inspection should be made for cuts or nail holes in the lead armor where moisture is liable to enter and destroy paper insulation. Be sure that cable ends are securely fastened to reels.

Cable reels must always be rolled in such a direction as not to unroll the cable. Most manufacturers paint an arrow on the side of the reel to give the direction for rolling. In lowering the reels from the car to the ground or trucks, skids must be used and reels should be lowered slowly by "snubbing" the free

Fig. 130.—Two reels of cable on truck-men laying rope over reels.

Fig. 131.—Rope is drawn tight over reels, holding them in place.

end of a rope passed around the reel. This, of course, is not necessary when the truck bed is on the same level as the floor of the car. Blocks should be placed in readiness so that reels will be under control at all times. Figure 129 shows a truck with one reel of cable in place and the second reel about to be lowered

on the truck. After the two reels are placed on the truck the pulling rope is fastened to the rear of the truck and rope is placed over both reels and tightened up with a power winch. Blocks are used in addition to prevent reels from rolling. Figure 130 shows men placing a rope over the reels. Figure 131 shows the rope being drawn up tight.

In no case should the reel be dropped even a short distance. When skid boards are used they should be propped up at one or two points by blocking or wooden horses made for this purpose. A man should be placed on each side of the reel being unloaded with a block to be placed in front of the reel to stop it at any time for straightening and to avoid accidents. Figure 132 shows the truck unloading a reel on the street. The rope is passed

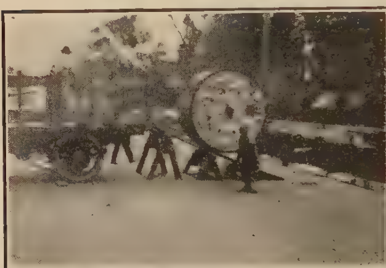


Fig. 132.—Unloading reel on street.

Fig. 133.—Raising reel that had been tipped over.

around the reel and fastened to the back of the truck, the other end is on the power winch. Figure 133 shows the raising of a 3-ton reel of cable which had fallen on its side. The reel is first jacked up about 8 or 12 in., then the reel bar is passed through the reel. The rope from the power winch on the truck is passed over the reel and hooked on the reel bar on the lower side. The power winch slowly raises the reel while the plank and block are placed to prevent the reel from rolling sideways.

Placing of two reels at alternate manholes makes it convenient to pull cable and set up the reels. Of course, it is necessary to plan on using the most convenient manhole to pull from. Placing two reels at alternate manholes allows the truck to make two or more pulls at one manhole. If two cables are being pulled in, four pulls can be made from the same point. Reels should be placed in the least conspicuous place on the street and if possible should be placed on the walk near the curb or in the parking

between the curb and walk. Red lights should be placed so that they can be easily seen at night.

Rodding and Cleaning Ducts.—After the duct is assigned, the rodding foreman, before drawing in the cable, must draw a mandrel through the duct to find out if it is clean and contains no obstructions. This mandrel must be not more than ¼ in. smaller than the duct and at least 30 in. in length. It should be made of iron or wood and should be rigid and not flexible. After the duct is rodded the mandrel can be fastened ahead of the rope when the rope is being pulled in. If the mandrel cannot be drawn through, the obstructions must be removed. Dirt or sand can

FIG. 134.—The proper position of reel when pulling in cable.

FIG. 135.—Pulley on manhole top and duct pulley.

be removed with a steel brush and mud can be removed by using a ¾-in. pipe and a steel brush. The short section of the pipe connected to the brush should have small holes drilled in it so that when the city water pressure is turned on the water will soften the mud and the brush can be used to loosen the mud and brush it out. Small amounts of concrete can be removed from the duct by tools specially made for this purpose, but in some cases it will be necessary to excavate to remove the obstructions.

Place the reel on that side of the manhole at which the cable enters the duct so as to allow the cable to enter the manhole from the top (never from the bottom) of the reel, thus allowing a simple curve from the reel to the duct without danger of abrasion, sharp bends, or kinks (see Fig. 134). Raise the reel on jacks and remove the lagging. Do not pry against the lead sheath or otherwise touch it. Rather pry on the edge of the reel. A man with a wooden pry should be on each side of the reel working

together with two other men on the opposite side of the reel to turn it. See that all nails are removed from the edge of the reel and that the lags are put in a safe place to prevent stepping on nails in them or stumbling over them. Inspect the end of the cable carefully before pulling in to see that it is properly sealed. There may be moisture in the duct, and, if the end of the cable leaks, there is danger of water or moisture entering and destroying the paper insulation.

Pulling in Rope.—Fasten the mandrel on the rodding wire and the rope to the other end of the mandrel. This precaution is

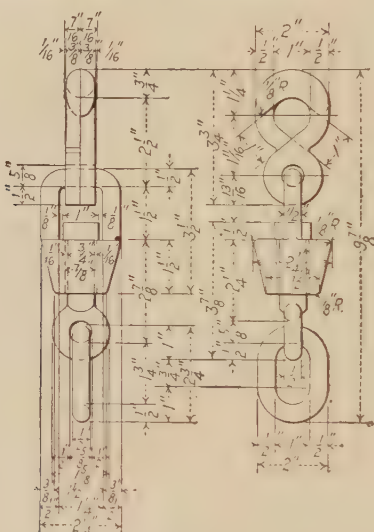


FIG. 136.—Working drawing for sister hooks and swivel.

taken to avoid the possibility of the rodding gang missing a duct. It is better to be sure than sorry, and besides, some time may have lapsed since the rodding gang mandreled the duct, and excavations may have been made in the street by workmen on gas or water services, thereby damaging the duct. The cable crew then proceeds to pull the rodding wire at the reel manhole to eliminate friction of the wire at edge of the duct and on top of the manhole. A pipe tube is placed in the duct with a pulley attached to the end which projects into the manhole at an angle of 45 deg. The wire is passed through this pipe and pulley and another pulley is placed on top of the manhole which has its bearing between two angle irons which are placed across the top of the

manhole. The wire is passed over the pulley. This system not only saves the wire but makes an easy pull which speeds up the operation. Figure 135 shows these pulleys. After the rope is pulled through to the reel of the cable, a metal feeding tube is placed over the cable and the cable grip is then placed over the end of the cable. The rope is fastened to the grip by sister hooks and a swivel (see Fig. 136). The end of the cable is allowed to be lowered into the manhole. The slack rope is taken up at the winch end. The end of the cable enters the duct for the full length of the grip, then the feeding tube is placed in the mouth of the duct. Now the cable is ready to be drawn in. Note

FIG. 137.—Putting cable grip on cable.

the feeding tube in Fig. 134, and placing the cable grip in Fig. 137. A very important part of this operation is to inspect the cable as it is being fed into the duct. This can now be done on top of the manhole. Two men in back of the reel can watch the top of the cable as it is unreeled and another man in front of the reel (that is the side of reel nearest the manhole) inspects the underside of the cable as it is passed into the feeding tube; another man places grease on the cable as it is passed into the feeding tube. The feeding tube prevents any sharp bends while pulling the cable and prevents the lead sheath from being damaged by coming in contact with the side of the manhole casting, hangers, etc. When the cable reaches the pulling manhole, sufficient slack should be left to make a splice and the ends of the cable should be very carefully inspected for cracks where

water may enter before the cable is spliced. The foreman should be responsible for this and see to it personally. Cable costing from $1 to $3 per foot can be damaged so as to cause the loss of a complete section, amounting to several thousand dollars. If the foreman finds that moisture has entered, he should have the cable splicer boil out the moisture if possible and properly seal the cable before leaving it.

Protectors or duct shields should be placed in the ducts by the cable crew at once so that the lead sheath will not be damaged at the edge of the duct. The cable should not be racked around

FIG. 138.—Five ton truck used for pulling cable.

the manhole by the cable crew but they should leave the ends supported or tied in such a manner that the cable will not be in the way when entering the manhole. Stepping upon, bending, or allowing cables to sag may cause the paper insulation to break. Cable splicers should do all cable racking, bending, or training around the manhole.

Paper-insulated cables are filled with an insulating compound care, which thickens and becomes stiff in cold weather. Great therefore, should be taken in bending cable when the temperature is below freezing unless the cable is previously warmed. Otherwise the insulation is likely to crack and thereby ruin the cable. Figure 138 shows a power winch on a 5-ton truck in operation pulling cable.

Rigging in Manholes.—Wherever possible, pulling eyes should be built in manhole walls to hold snatch blocks in place, to simplify the rigging for pulling cable. Rigging as shown in Fig. 139 can be used in the most difficult places but of course this makes it necessary to haul a large number of heavy blocks around on trucks. A rigging as shown in Fig. 140 can be used. This

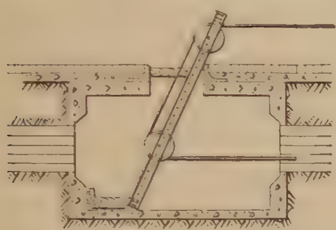


Fig. 139.—Manhole rigging using a snatch block.

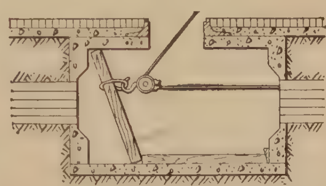


Fig. 140.—Manhole rigging using two "I" beams, with large pulleys.

rigging has proved very satisfactory in shallow manholes. In any case foremen should inspect rigging at all times to prevent injury to employees and to prevent damage to working cables in manholes. Improperly placed rigging may give way when least expected and cause considerable damage (see Fig. 141).

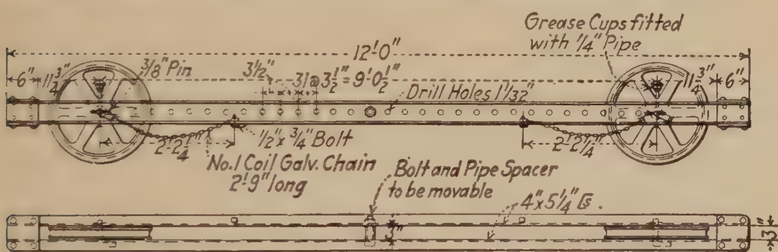


Fig. 141.—Working drawing of pulley rigging.

Sealing Cable Ends.—It has been emphasized that the ends of cables or seals should be tight to prevent moisture entering and damaging the paper insulation. The manufacturer will often ship more than one length on a reel and it then becomes necessary to cut the cable when installing it. After the cable is sawed off, both ends should be sealed at once. First, have the end that has been pulled in straightened up and leveled; the end on the reel should be allowed to roll back and be leveled. Do not bend the cable. Now use a sharp jacknife to cut the insulation next to the lead. If it is three-conductor cable, all

of the belt should be cut away, the copper can be slightly hammered back on the ends; then carefully scrape the edge, rub with stearine wax, and tin the lead very carefully. Do not attempt to fill the end up with solder before tinning. Such a seal will leak and cause the loss of the length of cable. After you are sure the lead is tinned all around, then flow in half-and-half solder until the end is filled. Float the solder smooth with a hot soldering iron. Be sure that there is not a fine piece of paper insulation sticking up through the seal or a fine pinhole. Examine carefully before you leave it. Another method is to put a paster around the cable after the lead is tinned placing it 1/8 in. higher than the end of the lead. Then float this space full of half-and-half solder. This method adds more metal to the end and insures a tight seal.

Pulling Eye.—The usual method has been to use a wire grip for attaching the pulling rope to the cable when insulating it in the duct. The pulling stresses on the cable while being installed should be taken into account, and, for large cables being installed in small ducts, the stress on the insulation is great. Take, for example, a three-conductor, 400,000-cir. mil cable with 13/64- by 13/64-in. paper insulation and 9/64-in. lead, the cable weighing approximately 13 lb. per foot and the outside diameter being 3.25 in. This cable was installed in a 4-in. duct. The lengths varied from 300 to 400 ft. A dynamometer was placed in the pulling line and it was discovered that there was a steadily increasing stress on the cable which did not exceed 4,000 lb. except in one case where a short length indicated 5,000 lb. It was also discovered during the installation that by a slight manipulation of the cable at the feeding end, the reading of the dynamometer could be raised 2,000 lb. or more. This condition was caused by too much or too little slack at the feeding end.

Another test was made with a wire grip connecting the cable to the pulling rope. The lead was stretched permanently 2½-in. on a 2,900-lb. pull, breaking the lead sheath. Another test was made on the same class of cable and duct. A pulling eye was properly attached to the end of the cable and was subjected to stresses up to 10,000 lb. without any affect on the electrical tests on the cable. This test seemed to indicate that the pulling eye in the end of the cable properly connected to the copper, and lead is the safest means of connecting the cable to the pulling rope. There are many ways of making the eye in the end of the cable.

Some manufacturers furnish the eye installed on the cable at an extra charge, but it can be made by a jointer on the job. A simple method is to cut off 18 in. of lead and when ringing the lead at the 18-in. point, cut clear through to the copper. Remove the lead, then split the lead on the cable about 3 in., bending these strips back. Now remove all the insulation as far as possible, then bend the three conductors back to the lead. It will be necessary to cut out the center core of copper conductor about 6 in. leaving the outside strands full length. Now, wrap each conductor around the three conductors near the lead, then carefully sweat with half-and-half solder. Care must be taken to tin the copper well so as to get a good bond. Now bend the lead strips over the copper, dress them down smoothly, and shave. Then wipe the lead to the copper. Care must be taken with the loops to see that an equal strain will come on each conductor. The eye should be water-tight as well as strong.

CHAPTER VIII

UNDERGROUND STREET-LIGHTING SYSTEMS

The series system is the most common in this country for arc and incandescent lighting. There are a large number of multiple circuit systems in operation and a number of small whiteways which are installed in small cities installing iron conduit and rubber-covered wire, or rubber-insulated lead covered cable. Fiber conduit installations are also used for street lighting installing lead covered cables in same. In some cases rubber insulated cable without lead has been used. Due to the high cost of conduit construction for street-lighting systems, steel-tape cable was developed to insure a safe and inexpensive installation. Large installations of this type have been made in our small towns, city parks, and boulevards. The steel-tape or armored cable consists of a double taping of mild steel between two wraps of asphalted jute. The inner wrap acts as a cushion between the cable and the armor and, with the asphalt compound, protects against corrosion. The two tapings of band steel are applied in the same direction, the outer tape covering the points between the turns of the inner tape. The final wrapping of asphalted jute protects the armor from corrosion. This type of cable is buried in the ground without the expense of conduit construction. Another type of cable for underground street lighting has been developed for series incandescent lighting. This is the paper-insulated lead-covered cable with one layer of jute and asphalt and two layers of braid and asphalt. This cable is lower in cost than the steel-tape cable and has proved successful. The jute and braid offers comparable mechanical protection and also protects the lead from chemical and electrical action.

Installation of Street-lighting Cable.—There are various methods of installing cable in the ground without conduit. This can be accomplished by the plow method which consists of plowing a trench, laying the cable in the trench, and covering it over. One company uses a plow developed by them which is so constructed that the plow is started directly at a lamp post.

The cable is made fast to the bottom blade of the plow so that it is drawn in underground as the plow proceeds. This plow has a sod cutter in front and a roller attached at the rear. The roller puts the sod back in place. A power winch or tractor winch is used to pull the plow. It seems that this method would be very successful in unpaved streets or grass spaces where there are no large trees, though tree roots will prevent its use. The usual practice is to bury the cable close to the curb in the grass space, in cement walks, or under the street paving. Under these circumstances the plow cannot be used. In order to install street-lighting cable economically, the trench must be excavated very narrow so that the least amount of sod and soil are removed, yet protection of the cable must not be sacrificed. Local conditions may compel the installation of the cable under the street paving close to the curb. The cable should be placed at a depth that will prevent it from being crushed by heavily loaded trucks, etc. Another objection to the method of placing cable close to the curb under paving is the possibility of breaking the water seal between the curb and the paving. The great cost must also be considered of repaving a trench with 8-in. concrete base with brick or other paving. A narrow cut can be made in the cement walk close to the curb. If the cutting is carefully done in a straight line the cement can be replaced and marked neatly to correspond with the original sidewalk, but where the new cement joins the old walk it should be marked in a straight line paralleling the curb. This will give an indication to men working on the streets in the future that a cable is present.

It has been the writer's experience that the best-protected cables are liable to damage by men excavating for water or gas services. Gas men have drilled through an eight-duct conduit and struck the high-voltage cable in the bottom duct. In another instance, a service entering a hotel, consisting of 3½-in. iron pipe surrounded by 3 in. of concrete had a pointed bar driven through concrete, pipe, and cable. This naturally short-circuited the cable and left the hotel without service until it could be repaired.

A danger warning stamped on each permit taken out by the contractor, plumber, or other person excavating in streets has proved very successful and has cut down this trouble to a great extent. Another feature which has helped is to bill the person responsible for the damage, urging prompt payment of the bill.

Underground street-lighting systems, if properly planned in advance, can be installed at a fair cost compared with overhead installation on trolley poles or wooden-pole suspension.

Installing Concrete Bases.—A crew consisting of a foreman and 15 men is desirable for installing the bases for posts. A handy man marks out the holes to be dug at points along the route, which has previously been staked out by the engineers or public officials. The holes are excavated 24 by 24 in. and 30 in. in depth. Six inches at the bottom are flared out. After laying out 20 or more holes to be dug, this man set a template over each hole already dug. This template holds in place the anchor for

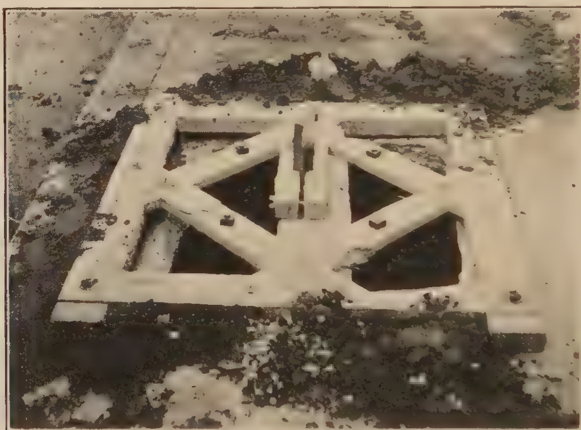


FIG 142.—Bottom template used to make groove in concrete base for cable.

the cut-out and the four bolts to fasten the lamp post to the concrete base or footing. On the underside of this template two quarter-circular forms are fastened to make the slot in the concrete for the cable entrance in the lamp post. The complete set-up is shown in Fig. 142 in place ready for concrete. Figure 143 shows the bottom side of the template with the slot forms.

Concrete Crew.—A concrete crew follows the operation of installing templates having a $3\frac{1}{2}$-ton truck to haul rock, water, and cement. A trailer is attached to the truck which hauls water and sand, and attached to the trailer is a concrete mixer. There are a foreman, three laborers, and a driver in this crew for pouring the concrete bases. This foreman has in charge a subcrew who remove the templates after the concrete has set for

12 hr. This takes two laborers and a finishing crew who are cement finishers. They face up the bases so that when completed they are level and smooth. Figure 144 shows the truck, trailer

FIG. 143.—Template in place with cutout anchor in place ready for concrete.

and concrete mixer getting ready to move to the next base. Figure 145 shows the base completed with bolts and cut-out anchor in place.

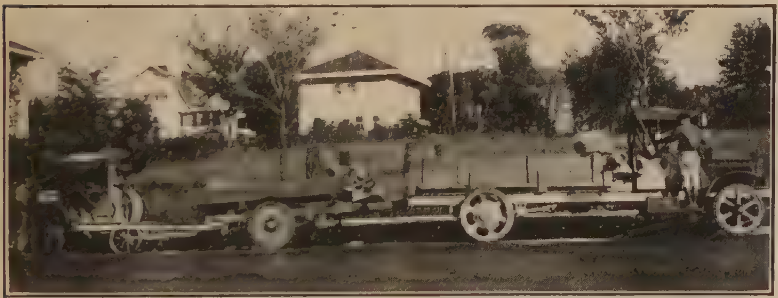


FIG. 144.—Truck, trailer, and concrete mixer for mixing and pouring concrete bases.

Trenching.—The trench crew consists of a foreman and about 40 men. When the trench is in grass, no picking usually is necessary. A narrow spade about 3 in. wide especially made for trenching is shown in Fig. 146. The depth of the trench is 18 in. close to the curb: or where the lamp posts are installed

near the walk, the trench is dug in line with the lamp post. After the trench is completed, clean sand is placed in the bottom to a depth of 3 in. After the cable is installed, the same quantity is placed on top of the cable. Figure 147 shows a trench in hard, rocky soil close to the curb. Crossings at intersections were made by open trenching and fiber conduit installed and surrounded by 3 in. of concrete (see Fig. 148). This method, however, has been abandoned and an auger or pipe-pushing machine is now used to make a hole about 30 in. below the paving through which the cable is installed. When using the auger method, it is necessary to excavate the trench about 18 in. wide and about 6 ft. long and 1 ft. deeper than the desired auger hole. This is working space for the man operating the auger. In hard clay it is well to use water on the auger. This softens the clay and speeds up the operation.

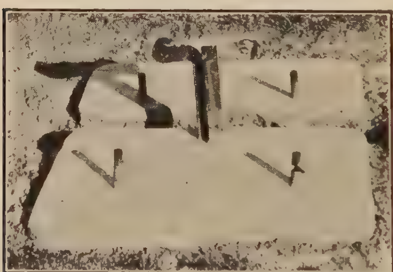


FIG. 145.—Concrete base complete, showing anchor and bolts in place.

FIG. 146.—Special spade for digging narrow ditch.

When using a pipe-pushing machine, a ditch 24 in. wide and about 8 ft. long is dug and the machine is placed in the trench at the depth desired. Level and square up the bottom of the trench so that it has the proper level and direction in which the pipe is to be pushed. The sighting is the difficult part of the operation and great care must be taken so that the pilot will reach the designated point. A length of pipe is placed in the vise jaws and the pilot is coupled to the pipe. The pilots are made hollow so that water under pressure may be forced through them. This makes the pushing much easier. The pipe is then pushed across the intersection. The cable can then be made

FIG. 147.—Trench excavated in hard soil.

FIG. 148.—Installing fibre conduit at intersections.

FIG. 149.—Pipe pushing machine and augers used for crossing under paving.

FIG. 150.—Cable crew and truck laying cable in trench.

fast to the pilot and pulled in as the pipe is pulled out. Figure 149 shows a pipe-pushing machine. All intersection work is taken care of by the foreman who does the trenching. Of course, it is necessary to pick out handy men for this kind of work.

Installing Posts.—A 5-ton truck is used to haul the posts from the freight cars to the base upon which they are to be set. The truck crew unloads from the truck. Two handy men are ready to place the post on its base and the nuts are placed on bolts.

Fig. 151.—Cable laid in trench.

Fig. 152.—Terminal pole with R.-O. transformer potheads and cable.

This crew is followed up by two men who permanently set the posts by plumbing them and tightening the bolts.

Installing Cable.—After the trench is completed, the intersections piped or made otherwise, and the posts installed, the cable is laid in the trench. The 5-ton truck will hold four reels of cable, making a total of 8,000 ft. of cable. One reel is jacked up on the truck ready for installation.

The cable crew consists of eight men and a foreman who start at a lamp post and pull or unreel cable as they go. The cable is laid in the trench and cut and sealed at each post, allowing enough slack to make connections to the cut-outs. Figure 150

shows a cable crew with truck and cable, installing cable. Figure 151 shows the cable laid in the trench. After the cable is laid, a 3-in. sand covering is placed, the trench is backfilled, the sod replaced or the cement walks refinished whichever the case may require. The sand is placed round the cable for the purpose of keeping the earth surrounding the cable dry. Also the sand will allow the cable to expand and contract with temperature changes.

Over 800,000 ft. of No. 8 single-conductor lead and braid cable for underground street-lighting purposes has been installed as above and has given good service for over 3 years. Figure 152 shows a terminal pole with cable, potheads, and R.-O. transformer installation for underground street lighting.

The following table shows the time required to excavate a trench 18 in. deep and 3 to 4 in. wide for underground street-lighting cable.

Time for excavating in dirt:	
Average amount excavated per hour by 1 man.......	15.10 cu. ft.
Average amount excavated per hour by 40 men......	604 cu. ft.
Average amount excavated per 9 hr. by 40 men......	5,436 cu. ft.
Time for excavating in dirt containing loose rock:	
Average amount excavated per hour by 1 man.......	13.33 cu. ft.
Average amount excavated per hour by 40 men......	535 cu. ft.
Average amount excavated per 9 hr. by 40 men......	4,815 cu. ft.
Time for excavating in shale and rock:	
Average amount excavated per hour by 1 man.......	9.94 cu. ft.
Average amount excavated per hour by 40 men......	398 cu. ft.
Average amount excavated per 9 hr. by 40 men......	3,582 cu. ft.
Time for excavating in sidewalk 4 in. thick:	
Average amount excavated per hour by one man.....	7.98 cu. ft.
Time for excavating in sidewalk of solid concrete:	
Average amount excavated per hour by one man.....	2.92 cu. ft.
(This was done by hand.)	
Time for excavating in sidewalk of solid concrete using portable air compressor:	
Average amount excavated per hour by one man.....	5.62 cu. ft.
This was done with air compressor.	
Approximate amount of street-lighting cable installed per day..	8,000 ft.

LAYING CABLE ECONOMICALLY BY SPECIAL PLOW[1]

A special plow built for installing parkway cable in the grass plots between curb and sidwalk in residential streets and on

[1] J. W. Sylvester Superintendent Alternating-current and Arc Underground Lines, Philadephia Electric Company.

private property has been very successfully used by the Philadelphia Electric Company. This company has installed many miles of cable by this method on the boulevards in Philadelphia and has used it in a number of suburban towns for incandescent street-lighting purposes. Long underground services on private property have been installed with perfect success. In all of these installations the ordinary lead-covered cable has been used, it being found unnecessary to resort to steel-armored cable. The company fully believes that this method has been justified because of the exceedingly low cost of maintenance of this type of installation.

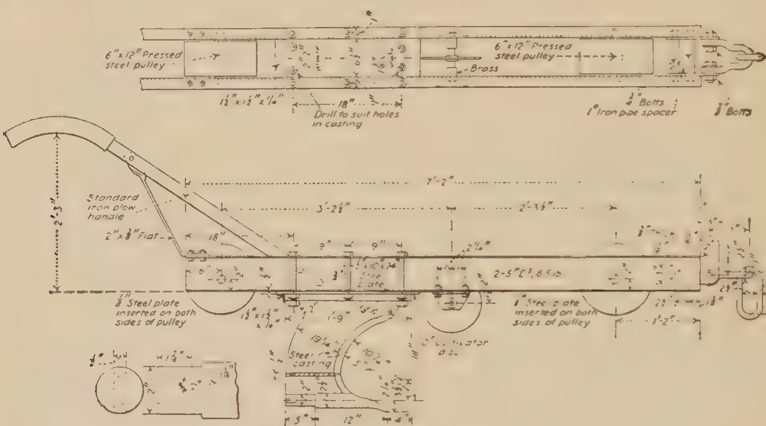


Fig. 153.—The Philadelphia plough.

In laying cable by this method a hole about 18 in. deep by 2 ft. square is dug at the point where the cable plow is to begin its work. The cable is attached to the rear end of the torpedo-shaped prong which forms the lower end of the plowshare, about 18 in. in front of which is a harrow disk which serves to cut the sod in front of the plowshare. The plow is drawn along the surface of the ground by means of a cast-steel running rope attached to a gasoline-driven winch, which is secured to the ground at a point in the distance to which the cable plow is drawn. This distance is usually not over 600 ft., although cable has been pulled in this manner a distance of 800 ft. The longer distance is not, however, recommended. As the plow is drawn toward the winch it drags the cable through the ground, the cable being fed to the plow through the hole in the ground mentioned above. Figure 153 is a plan of the plow.

The usual size of a crew on this work is six men and a foreman, and as high as 4,000 ft. has been installed in a day with such a crew and this equipment. Unless the plowshare encounters large stones in its progress through the ground, the only evidence of it seen on the surface will be a small, slightly raised seam in the sod about 1/2 in. wide. By means of a tamper this is readily restored to the original grade, and the work is so neatly done that unless one were looking for it, it would be imperceptible. Of course, if the plow meets with stones, it usually results in the tearing up of the sod, but this can be readily remedied.

At the time this plow was designed, tractors had not come into economical use, but the writer feels that in place of a cumbersome gasoline-driven winch a tractor could be used which would be very much more satisfactory. He has no doubt that with a tractor the 4,000 ft. per day could be readily increased.

CHAPTER IX

INSTALLING SUBMARINE CABLES

Submarine electric-power cable for transmission and distribution is now almost as common as underground land cable and is used to transmit power across a river or stream. There have been many installations of submarine cable made in the past 25 years in New York City, Boston, Philadelphia, Minneapolis, St. Louis, and in California. Installations have been made using voltages ranging from 110 to 33,000 volts. Various designs of cable have been made some using rubber-insulated conductor with galvanized steel tape and two layers of jute impregnated with asphalt. This is covered with No. 6 B.W.G. galvanized-steel armor wire and covered with two layers of jute impregnated with pitch and with soapstone finish. In another cable the conductors are tinned-copper strands and are insulated with 30 per cent Para rubber compound and wrapped with several varnished-cambric tapes. The insulated single conductors are stranded with saturated jute fillers to make a circular section and a belt or jacket of varnished-cambric tape placed over all. A lead sheath is then applied and the cable is covered with jute and galvanized-steel wire.

The Paper-insulated Cable.—This has a lead sheath and two layers of jute impregnated with asphalt and galvanized-steel armor. Many submarine cables have been installed in the past without jute covering over the steel armor, but the present method is to cover the steel armor with two layers of jute impregnated with asphalt or pitch and finished with soapstone to prevent sticking.

Installing Submarine Cable.—There are several methods for installing submarine cable. The method will depend upon local conditions, that is the width and depth of the stream, the condition of bottom, and the obstructions, the boat traffic, etc. A large cable to be flexible enough to handle cannot be made in very long lengths. This must be taken into consideration for handling purposes from the factory to the place of installation. If the

length is shipped by boat to the point where it is to be installed it can be easily handled. This is not always possible and when handled by rail there is the question of unloading from freight cars to trucks, transporting to the river and loading on boats. When the weight of submarine cable lengths is considered which may be from 8 to 18 tons, it is wise to plan carefully the whole submarine job. Splices in submarine cable should be avoided if possible, but of course this cannot always be done. If the total length across the stream is approximately 1,000 ft., the cable can be installed in one length without difficulty, that is, no splicing is necessary. But when it is necessary to install

FIG. 154.—2,400 feet of Submarine cable.

a three-conductor, high-voltage submarine cable across a stream 2,000 to 4,000 ft. across, it is necessary to splice the cable.

Unloading.—When unloading the cable from freight cars to boats, it may be necessary to use a derrick or a crane. The boats should be of ample size to handle the heavy cable. This matter should be taken up with a local boatman who understands the handling of heavy barges with heavy cargoes. When loading reels of submarine cable, care must be taken to place them in the center of the boat or barge or at least to distribute the load evenly to prevent listing as this may cause serious trouble if not taken care of before starting across. Of course, weather conditions must be taken into consideration as it is almost impossible to keep a straight course across a river or lake with a stiff breeze blowing down- or upstream. As mentioned in the beginning,

local conditions control the operation to a great extent and these must be met as they arise. It is necessary to take soundings of the stream at least every 10 ft., to note the condition of the bottom for rock, mud, or sand, the location of the cable landings on each side, the tides or flow of the water, the depth, etc. This information should be placed on a map and should be used while installing the cable and for future record. A submarine cable may be installed by running a steel hawser across the stream, thereby guiding the boat across. A stationary donkey engine with a "nigger head" on the boat may be used to pull the boat across and unreel the cable from the reel as the boat moves along. For narrow streams, a cable may be pulled across, but this is not practical for very heavy cable. Most submarine power cables are laid rather than pulled. The reel is usually set up in the center of the boat on heavy jacks or timbers made into a crib so that it will not shift from one side to the other. This crib should be bolted together firmly and bolted to the deck of the boat and a heavy shaft passed through the reel. Care should be taken to have this heavy enough to carry the weight of the cables. The end of the cable should be passed over the top of the reel to the stern of the boat. A set of large pulleys should be placed there to guide the cable as it is laid out and to prevent sharp bends. To guide the boat in a straight course it may be necessary to have an anchor cable parallel with the intended course to fasten guide ropes to and to be shifted along as the crossing is made, or a tow boat may be used to nose alongside of the barge on the downstream side, thus keeping the barge in its course. It may be necessary to use more than one tow boat, depending upon the flow of the stream and the size of the barge.

Before starting across, the end of the cable should be made fast on shore allowing a generous amount of slack while the cable is being installed. After the cable is laid to the other side, the rope holding the cable fast to each side should be slacked off but securely fastened to some stationary anchor to allow the cable to settle in the bottom of the river where there is sand or mud, so that when the land cable is spliced to submarine there will be very little strain on either cable. In some rivers where the bottom is shifting, heavy anchors have been used and slack left in midstream. The writer has installed a number of submarine cables in various parts of the United States and does not believe this practice is necessary with heavy cables. This may be desir-

able in the case of a small cable, but it would seem that a cable weighing 28 lb. per foot would in a very short time settle down into the river bed to such a depth that it would make for itself a permanent place. In fact, that has been the writer's experience. On one installation a large river dredge was used to make a trench about 12 ft. wide in which 11 cables were laid, and, after the cables were installed, a diver was sent down to inspect them. He found them covered with mud and sand. These cables have been in operation for over 20 years and are still operating. No shifting has been noticed.

When it is necessary to use more than one length of cable to make a crossing, the number of lengths neccssary to complete the circuit should be loaded on one barge so that when one length has been laid, the barge may be securely anchored and the second length spliced to the first. The anchoring at this stage of the operation is very important and too much care cannot be taken. Heavy anchors of the proper design must be used for the locality, taking into consideration the material of the river bottom, and even after the barge is anchored it may be necessary to have tow boats nose the barge to keep it in place. All precautions should be taken to guard against heavy winds and storms. In case of a storm it may be even necessary to drop the end of the cable and bring the boats to shore until calmer weather prevails. If this is done, a buoy should be made fast to the end of the cable and proper signals placed thereon to warn vessels of danger. While the barge is anchored, and during the splicing operation, signal flags and lights should be placed on the boats.

When planning to install a submarine power cable, it is wise to take time to prepare the boats with all equipment which it may be necessary to use and a great many articles that may be needed in an emergency. It is well to remember that it takes time to move about in a boat. Anticipate your needs before starting out.

Splicing Submarine Cable.—Splicing submarine cable is similar to making a land splice, the only difference being the extra length of splice and the handling of the steel armor. The ends of the cable should be allowed to lap at least 6 ft., a band of iron or clamp should be placed around the armor about 2 ft. from the end of where the splice will be; then, if jute covering is over steel armor, without bending the wires—and to leave it in its original shape—pull it to one side to give splicer ample room to work. After the usual splice is made, wiped, and filled,

burlap or asbestos is wrapped over the lead sleeve and exposed lead cable, then hot compound or pitch is poured over this covering. The steel armor is then wound or laid back in the same manner it was, or removed; that is, it is laid back with the original layer and the ends are allowed to pass beyond the ends of the splice. The steel armor is then bound together with tinned-copper binding wire and soldered together by a wiped joint after which the burlap or asbestos is wrapped around the steel armor, and hot compound or pitch is poured over thoroughly to saturate it. After all is cool, some sort of reinforcing should be placed lengthwise with and over the splice so as to prevent bending the splice when lowered into water. This can be accomplished by using oak planks or two steel channels bolted together over the splice. This should extend at least 12 in. beyond each end of the splice. Another method used for submarine splice protection by the writer was a specially designed cast-steel split sleeve which is 12 in. longer than the splice. This is put over the splice and bolted together. A groove in the joint is filled with a rope packing. This sleeve is bolted together and there are two 2-in. holes in the top of the sleeve for filling purposes. This sleeve is then filled with neat portland cement. This makes a firm, solid job, and if the cast steel should rust or corrode, the cement will always protect the joint. When using the cast-steel sleeve it is recommended to leave off the burlap wrapping over the splice so that the cement will bond with the steel armor.

Method.—The question of laying all the cable first and then splicing has been advanced, but from the writer's experience the best method seems to be to lay a length and then splice the second length and then go on in succession depending upon the number of lengths required. There is not so much danger of twisting and kinking the cable by this method. On the other hand, if the splices are made after the cable is laid, it becomes necessary to drop the cable over the side of the boat in order to get it off the boat. This leaves slack and causes a twisting strain on the insulation.

Signals.—Permanent signals warning boats not to anchor should be placed on each side of the river or stream to indicate the location of the submarine cable. There is danger of anchors fouling the cable and damaging it. Large signs can be painted in red letters on the cable house, power house, or dock, or a sign may be erected for this special purpose using flood lights at night.

Land End.—When the submarine cable entrance is made directly into the power house or cable house, large-sized sewer tile can be used from the shore line into the building. This pipe should be laid as deep as possible so that the submarine cable

FIG. 155.—Two reels of 13,200 volt submarine cable.

will pass from the pipe to the river bottom without a short bend. The sewer tile should have a rope or heavy wire passed through it. This wire is made fast to a large piece of wood or an oil barrel. This will float and the wire can easily be found when

FIG. 156.—A submarine cable splice.

it is necessary to pull the submarine cable in. Care must be taken to prevent ice damaging the cable at the shore. Figure 155 shows two reels of 13,200-volt, three-conductor, paper-insulated lead and steel-armor submarine cable loaded on a barge ready to begin installation. These reels weighed approximately 8 tons

each. They traveled about 1,500 miles on a flat car. Note their condition. In order to unload them from the flat car to the boat, it was necessary to build large wheels and mount them on a heavy axle. This cable was installed in three lengths of 1,100 ft. each, making a total of 3,300 ft. across a lake in Minnesota. The depth varied from 10 to 35 ft. The bottom of the lake con-

FIG. 157.—Location of submarine cable in river.

sisted of clay and sand. One side of the lake was shallow and it was necessary to dredge a channel to the depth of 15 ft. to prevent ice damage in winter. The submarine cable at this point was pulled up a terminal pole. A trench was made about 3 ft. deep from the lake to the pole and the submarine cable pulled. The same method was used on the other shore where the cable

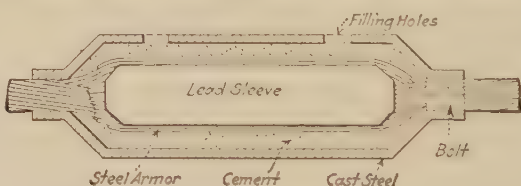


FIG. 158.—Cast steel sleeve over splice.

entered the substation. This cable was in operation for 12 years when the substation was abandoned. When the cable was pulled out, it was found to be buried all the way across from 2 to 3 ft. in the bottom of the lake. It was necessary to use a derrick to pull it out in places. This cable had operated all the time it was in service without failure. Figure 156 shows the splice before the jute and steel armor was laid over the splice.

Tow Boats.—Two tow boats were used for installing this cable, one holding the barge in the course and one towing. During splicing operations the barge was anchored. While the cable was being laid, a storm arose and it was necessary to drop the end of the cable. This, however, was not done until an oil barrel was made fast to an anchor and the cable made fast to the

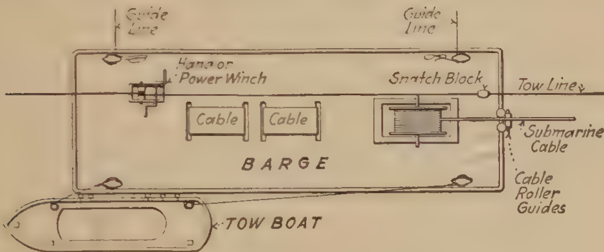


Fig. 159.—Boat equipment.

barrel. After the storm the end was easily pulled up. Figure 157 shows the Mississippi River at Minneapolis. At this location six 4 0, three-conductor, 13,200-volt, paper-insulated lead- and steel-armored cable was used. The cables were installed parallel with the stone bridge shown in the picture and indicated by the line marked "cable location." The bridge was used as

Fig. 160.—Laying 11,000 volt submarine cable across San Francisco Bay.

a guide, that is, a line was stretched across the river and at each pier of the bridge a rope was made fast to the crossing line. This method simplified the equal spacing of the cables across the river. The barge was propelled by the crossing line, a hand winch being used for power. The crossing line was passed over the nigger head on the winch. The reels were loaded on the

barge, and cable was unreeled as the boat moved along. One splice was necessary in the circuit. The depth to the river bottom varied from 12 to 50 ft. and it was composed of mud and rock, the rock being in the deep sections. Splices were made on the shallow side of the river. Figure 158 shows the cast-steel sleeve which was placed over the splice and filled with neat portland cement. Figure 159 is a diagram showing the barge, rope, etc. The tow boat is only employed when a tow line cannot be used. In the case described above, no tow boat was used. Guide lines were made fast to the bridge piers and moved ahead by men in the small boat as described. A brake is used on the cable reel to prevent the cable feeding into the river too fast. This is accomplished by inserting two planks under the edge of the reel. A man bearing down with his weight on each plank will handle the situation without any trouble whatever. As in pulling land cable in conduit, the crew who install the cable must be well organized and understand the signals given by one person, usually the foreman.

CHAPTER X

CABLE SPLICING

The modern underground-transmission or distribution-conduit system, designed in consideration of the size and voltage of the cables to be installed, together with the duct entrance to manholes, racking space, and hangers to eliminate unnecessary bends in the cable and provide means of installing the cables, is comparatively simple. When installing modern cables in old conduit and manhole systems is considered, the small or large rectangular manholes are not convenient for racking cables. In the small manhole, many short bends in the cable were made, while the large manhole had space and corners that could not be used. The small duct of the old constructuion, designed for small cables, did not take into consideration the need of heat dissipation or ventilation. The workmanship was poor, the joints were uneven, and there was not enough separation. In some cities tile duct was laid with a small quantity of lime mortar, and in many cases it was laid without mortar or concrete. This class of construction is hard on cables used for power purposes. Very rigid concrete construction for the conduit should be used. The modern auto truck becomes a factor here. The tremendous vibration caused by heavy truck traffic displaces or shifts the ducts and otherwise causes damage to the conduit system of the old type. A proper standard radius for bending cable should be adopted. Ten times the diameter of the cable is a good standard for a 13,200-volt cable. As stated, the **cable splicer,** or one who is trained in handling lead-covered cables, should do all the bending or racking of cables in manholes, and great care must be taken to bend cable slowly. The cable must not be bent with a jerk. Time must be allowed for the lead to stretch and to allow the paper insulation time to give in its layers. This is very important in cold weather. If the cable is cold it should be warmed. First, clean the lead, removing dirt or moisture, then pour hot compound over the lead armor until the cable is warmed throughout. Before bending wipe off all compound.

Splicing.—When bending cable do not use the duct to bend against. The cable should never bend less than 6 in. from the duct. Twelve inches is the best. The bending can be accomplished with the aid of rope, feet, and hands. At all times, while bending cable, a cable protector should be in the duct and should cover the cable all around, at top and bottom. This protector should be carried by the splicer for this special purpose and after bending is finished the protector can be replaced with a regular cable protector. Care should be taken when using the feet for bending, to see that no nails are in the shoes which might damage the lead armor. Buckling or kinking the cable will break the

Fig. 161.—Method of bending cable in manhole.

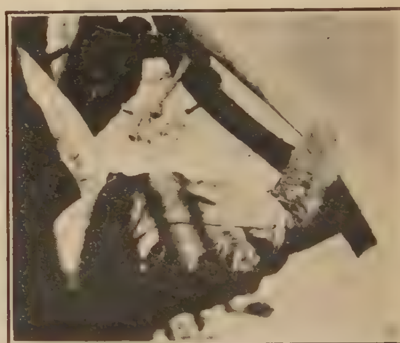


Fig. 162.—Method of bending cable in manhole.

paper or leave voids in the insulation. When short bends are made, the outer radius of the bend stretches the lead and the inner radius buckles, leaving air pockets. This air becomes ionized and in time will break down. For this reason, twisting cable ends in the manholes, while bending, should be avoided. Figure 161 illustrates a method used for bending a three-conductor, 400M, 13,200-volt cable. A hard-maple stick 4 by 4 in. is put in the adjacent duct and another in the duct above to hold up the weight of the cable. Three or four turns of ½-in. rope are laid around the sticks and cable. This, it will be noted, is about 12 in. from the duct and is where the first bend is made in the cable. While the rope holds the cable in place, the second bend is made by placing the sole of the foot against the cable at the point where the second bend is to be made (see Fig. 162).

The end of the cable is gently and slowly pulled from the wall, completing the second bend. It will be noticed that the manholes for this work are 4 ft. 6 in. by 11 ft. and egg shaped. The ducts enter the manhole close to the manhole wall, making only slight bends and giving plenty of room for splicing and racking the cables. This type of manhole makes cable work simple compared with a manhole such as in Fig. 163. To rack cables properly in a manhole of this type is a task which takes many hours of study. This manhole, no doubt, was originally installed

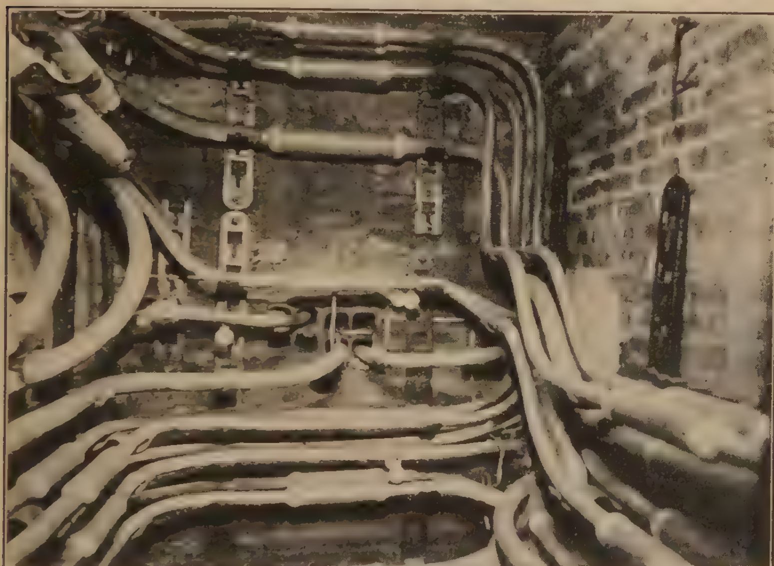


FIG. 163.—A difficult cable racking job.

for the capacity of eight ducts, and, as the distribution system grew, a conduit was installed as shown on the right of the picture and on the left and still another near the bottom of the manhole. When these additions were made it was necessary to rerack the cables. This kind of situation causes congestion and crowding of the cables and is a difficult cable job to perform without short bends. All so-called bending tools for bending cables are dangerous. There is danger of kinking or damaging the lead. The writer has in mind a bender made of a section of iron pipe with a handle. This is slipped over the end of the cable and bends are made with it. Also, the wood-bending stick with a hole in one end is dangerous and should not be used.

Removing Moisture.—The cables are usually left by the cable-pulling crew, without making any attempt to rack them. It is therefore the jointers first duty to inspect the cable thoroughly, from the edge of the duct to the sealed end, to discover any injury to the lead that may admit moisture. When the ends of cables are exposed to water in manholes for a long time, there is danger of water leaking into the sealed ends, due to poor workmanship or a broken seal. A careful examination should always be made to discover flaws in the sealed ends, and to examine them for moisture. This can be done by cutting off the seal. If moisture cannot be found by the sense of touch, a small piece of paper insulation can be cut off and tested in hot splicing compound, oil, or paraffin. Moisture is indicated by bubbles. If there is evidence of moisture, and when the cable can be cut off, a good plan is to split the lead lengthwise and bend it open a little, forming a trough, into which the hot compound can be poured until all the bubbles disappear. If moisture seems to be coming from that part of the cable which has not been opened, more lead should be cut back and hot compound again poured over the insulation. If it is not possible to cut back further, the lead should be carefully wiped clean back as far as the duct, then hot compound should be poured over the lead, starting at the duct and working slowly and carefully toward the open end of the cable, the object being to drive the moisture out through the end. This method works out satisfactorily where the moisture has not entered beyond the manhole. If a large quantity of water has entered the cable, it is advisable to remove the length of cable and install another. This test for moisture should be made on both ends of the cables in manholes before proceeding to cut them off for splicing. An insulation test should be made on the length before splicing.

Splicing Three-conductor, 400M, 13,200-volt Cable.—When the cables are properly racked or trained around the manhole and placed in the cable racks ready for splicing, the ends should overlap considerably. Next, the center of the splice is located and marked on the lead, the cable is cut off at this mark, allowing the two ends of cable to butt together.

Removing Lead.—Twelve inches from each end, the lead is marked and ringed. This cut should not go through the lead but about half the thickness. This can be done with a chipping knife and small hammer. Care must be taken in this

operation to avoid cutting through the lead and damaging the insulation. Next, carefully and thoroughly scrape or shave the lead from the ring mark about 3 in. with a shave hook, taking care not to dig into the lead with the hook. By using a rasp for this work too much lead is removed which weakens the joint. The clean portion of lead is then thoroughly rubbed with stearine wax. To remove the lead sheath begin at either end. The lead is cut lengthwise of the cable, beginning or stopping at the ring cut. This is accomplished with the chipping knife by hammering off with the hammer, or it can be taken off with pliers.

Caution.—Never remove the lead until it has been scraped or shaved at the ring mark. If the lead is removed first and then shaved there is danger of getting lead chips on the paper or lodged in the layers of the paper.

Fig. 164.—Belling lead on cable.

Belling Lead.—After the lead has been removed, the lead should be belled out as shown in Fig. 164. The belling tool is made from a piece of red fiber ½ by ¾ by ¾ in., and is made in the shape of a gouge chisel. It is held at an angle of 45 deg. This does a very even belling job and does not injure the insulation. After belling is completed, examine the edge of the lead for sharp points. If there are any, they should be carefully removed with a knife or a shave hook. The edge of the belled lead should be smooth. Note in Fig. 164 the shaved portion of lead with the stearine wax and belling the tool.

Preparing the Lead Sleeve.—The lead sleeve is usually prepared by the helper and is just as important as any other portion of the splicing. The lead sleeve should be straight and round and free from dents or cuts. If the lead sleeve is dented or flattened, a drift plug should be driven through it, and while the plug is inside, the sleeve should be dressed out with a wood dresser (see 164*a*). After this is done the ends of the lead sleeve should be made straight with a rasp, so that the sleeve will be equal in length all around. This is necessary in order to get the sleeve to dress in around the cable evenly. When the ends of

the sleeve are not square, they will cause a one-sided joint. The sleeve should be rasped or shaved on each end for about 2 in. and rubbed with stearine wax. The lead sleeve is then slipped over one end of the cable and pushed back out of the way. Care must be taken to see that the cable is free from dirt or water so that the inside of the sleeve will not come in contact with it.

Jointing the Conductors.—First, make a cut 1½ in. from the belled end of the cable in the belt insulation, being very careful not to cut clear through to the insulation on the three conductors.

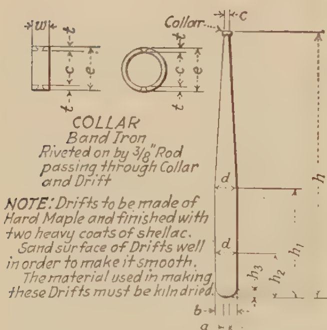


Fig. 164a.—Drift plug used to straighten lead sleeves.

Fig. 165.—Cutting paper insulation with cutters.

It is best to cut half through the belt, and then make a cut lengthwise with the cable, cutting the belt on an angle. Aim to cut between two of the conductors. After this cut is made, carefully remove the paper beginning at the end of cable by unwinding. When the belt is removed, cut the fillers, which lie between the conductors, at the point where the belt is cut. Now, straighten out the three conductors carefully; do not bend them as you may crack the paper, and after the splice is put in operation it may break down. The ends should butt together squarely and evenly. Remove 2 in. of insulation from each end with insulation cutters as shown in Fig. 165. Care should be taken here not to nick the copper with the insulation cutters, as this is likely to weaken the copper and reduce the conductivity. This may cause heating and finally a burn-out. The best method is not to use insulation cutters for this type of splicing, but to use a sharp knife with a

thin blade such as shoemakers use, pencil the paper almost to the copper, then remove the paper with a twisting motion. After the paper is removed for splicing, do not touch the copper with the hands. Scrape the ends of the wire, not the surface. The copper wire in a cable of this kind is bright and covered with oil or compound, and when a little stearine wax is rubbed on the copper strands it tins very readily. Do not use gasoline to wipe the copper strands because it is unnecessary, and there is danger of introducing moisture in its insulation as there is very little commercial gasoline that does not contain water.

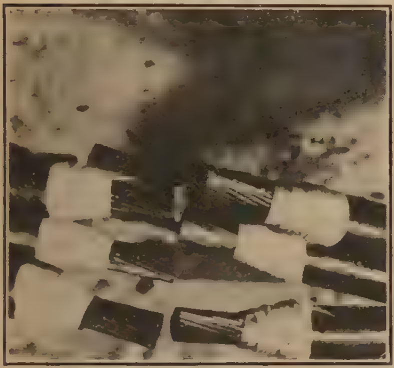


Fig. 166.—Cotton tape wrapped around paper insulation for protection.

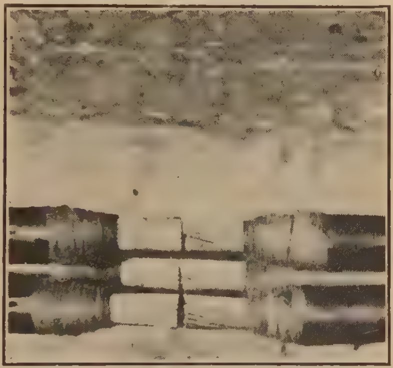


Fig. 167.—Ends tinned ready for copper sleeves.

Tape over Insulation.—After the ends are prepared for tinning, wrap the tapered insulation tightly down to the copper wire and over the insulation (as shown in Fig. 166) with clean, dry, cotton tape. This is done to prevent the solder from running under or between the layers of paper insulation and to prevent carbonizing it. The copper ends must be tinned before putting on the copper sleeves and for this work half-and-half solder should be used. Use two ladles pouring the molten metal over the strands with one ladle and catching it in the other. Continue this until the solder runs through the strands freely. Apply the stearine wax for a flux. Figure 167 shows the tinned ends. Care must be taken during this and the following operation not to bend the conductors near the crotch or where the conductors come out of lead sheath. The paper might be cracked at this point and a failure would be the result.

Sweating the Connector.—A tinned-copper sleeve or connector, which is tapered on each end and split lengthwise is expanded for the purpose of slipping over the ends of the conductors. After the three connectors are slipped on they should be pressed together tightly with pliers or a screw press. Thoroughly sweat together by pouring hot half-and-half solder over the connector, using two ladles, one pouring and one catching. The solder should run through the strands of cable freely, and, after it has run through, keep pouring solder until it begins to cool. When the connector is filled with solder, wipe off all surplus metal with a piece of cotton tape, which was previously laid over the conductor before sweating. A complete turn is made with tape long enough to hold each end in the hands pulling back and forth and dragging from each end of the connector to the other. This method will clean

Fig. 168.—The three conductors with copper sleeves in place.

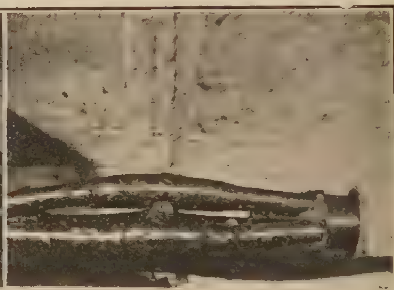


Fig. 169.—The three conductors insulated with paper tape.

the solder out of all small places such as between the end of the copper connectors and the paper insulation. The splicer must be absolutely sure that there are no sharp points of solder left on connector or cable. These projections or sharp points act as discharge points to induce punctures in the insulation. Fig. 168 shows three conductors ready for insulating.

Insulating the Conductors.—Before insulating the conductors, pour hot compound all over them, beginning at the end or near the lead and working toward the center on one side; then start from the other end and work toward the center. This will boil out any moisture that may have been left by perspiring hands or moist air in the manhole. This operation is accomplished by pouring compound with a kettle and catching the surplus compound in a saucepan. There are many methods used for insulating the splice. One is by various kinds of tubes, but at this time

only the hand-wrapped, paper-taped splice will be considered. At each end of the connector in this splice; a space of 1/8 in. is left where the paper is penciled. This is to enable the splicer to clean out the solder when sweating. This must be filled up before taping is begun. Then this space is filled with waxed twine, wrapping very tightly and evenly, but only enough to fill the gap between the connector and the end of the paper insulation, as shown in the working drawing for 400M, three-conducter 13,200-volt splice (see Fig. 172). The bare connector and penciled conductor are now insulated by wrapping with paper tape by hand. This paper tape is usually of the material used in manufacturing the cable, only that the paper tape is not more than 4 mils thick and 1 in. wide. There is no advantage in using lighter paper or less than 1 in. width. Paper tape 1/2 in. wide will not stand the strain put on it while wrapping tightly by hand. Insulation applied by hand is not so compact as that put on by machine and for this reason a greater thickness should be applied. A cable, with 14/64-in. insulation should have 21/64-in. insulation over the copper connectors.

The paper insulation used for this purpose should be purchased in small tins, holding about thirty-five 1-in. rolls of paper. The paper rolls are to be covered with petrolatum. Before using the paper, the tin should be warmed thoroughly so that the paper can be handled by splicer. Care must be exercised here to see that the paper is not overheated. Scorched paper should not be used. If it becomes carbonized it should be thrown away. The paper must not be wrinkled or cracked. Keep all dirt and moisture away from it. To insulate a conductor remove the cotton tape from each side and inspect the penciled ends for solder or scrapings, then apply petrolatum over the copper connectors and paper insulation. This should be put on in generous quantities over the penciled insulation and the waxed twine. To begin wrapping the paper tape, examine the small roll for dirt, then tear off the end or beginning of the roll. Start on the left end of the connector with the roll held between the thumb and index finger, letting the roll of paper revolve in the finger as it is rolled around the conductor, but enough tension should be used to insure smooth, tight wrapping of the paper. Lap the paper about 1/4 to 1/2 in. After each layer, more petrolatum should be applied with the hand, smearing it over the paper previously put on. The next layer will squeeze out the surplus. This will prevent air pockets or voids in the insulation.

The paper should be applied on the connector, first filling the space between the penciled insulation until even with the machine insulation, then each layer should run over the machine insulation about 6 in. each side of the center, making a total covering of 12 in. Great care should be taken at all times while this operation is going on to keep the hands clean and dry, free from lead, solder, or copper chips. When all three conductors are insulated as stated, a small roll of paper, such as is used for insulating, should be placed between the three conductors at each end of the splice and one in the center, and three other rolls in the center outside of the one between the conductors (see *a* and *b* Fig. 172). Then three belts are applied using 8-mil paper, 1 in. wide, one in the center of the splice and one on each side at a distance of 2½ in. on centers. The belts should be built up level with each other, to at least twice the thickness of the insulation of the cable. This is done to hold the conductors firmly together and to keep the lead sleeve from coming in contact with the insulation on the conductors, while putting the lead sleeve on. Figure 169 shows a splice insulated after all the paper work is completed.

Be sure and boil out the splice with hot compound to remove moisture. Now inspect the inside of the lead sleeve for moisture, slide the lead sleeve into position, dividing the distance evenly so that the sleeve will cover an equal amount of cable on each side. The sleeve should then be dressed in (as shown in Fig. 172) and the joint wiped on each end. This is a very important part of the splice. The joints must be made tight and wiped smooth. Solder, composed of 40 per cent tin and 60 per cent lead, should be used. This will make a tight joint which will not be porous if wiped at the proper heat. After the splice is wiped, two holes are cut in the sleeve with a knife and hammer as shown.

The lead sleeve should be shaved and stearine rubbed on before cutting the holes. One straight cut can be made and the edges lifted up with the knife and opened more by using a screw driver and beating upward with a small hammer. Pour the hot compound in one hole, using the other for a vent and overflow. When cutting these holes in the sleeve, hold the knife on an angle, so that when the holes are to be closed the lead can be dressed back in place, making a tight joint and preventing the solder from going through after the first filling. The splice should be wrapped with a paper or asbestos blanket (see Fig. 171) and allowed to settle for 1½ hr. The blanket will prevent the compound from

cooling too quickly from the outside and thus causing voids. The second filling should then be put in and the hole on the low end of the splice sealed with half-and-half solder. Pasters should be put in the sleeve in a neat square or oval. After ½ hr., pour more compound into the sleeve until it is full and the compound will not settle. The second hole can be dressed down and sealed with half-and-half solder and a soldering iron. Great care should be taken with the filling holes, to see that they are sealed properly.

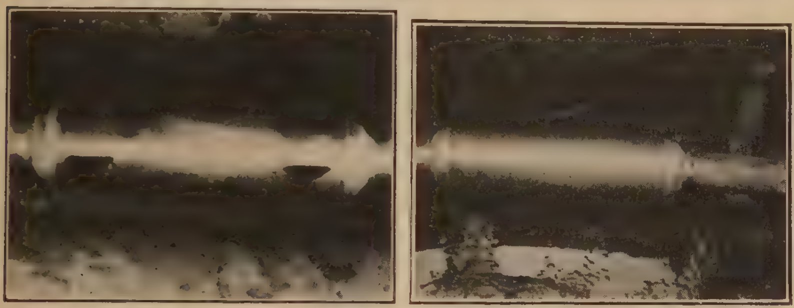


Fig. 170.—Completed splice.

Fig. 171.—Splice is wrapped with blanket to prevent cooling too quickly.

All other parts of the splice may be perfect, but if a very small spot of the seal is left and leaks enough to allow moisture to enter, the splice will fail. Carefully examine the seal and never be in doubt. It is better to spend a little time in sealing these holes than to have a splice fail.

The wipe joints of all splices should be marked with a steel stamp by the splicer, with his full name, for future identification.

The Four-conductor Splice.—A four-conductor, 3/0, 4,500-volt cable splice as shown in Fig. 173 is made up by the same method

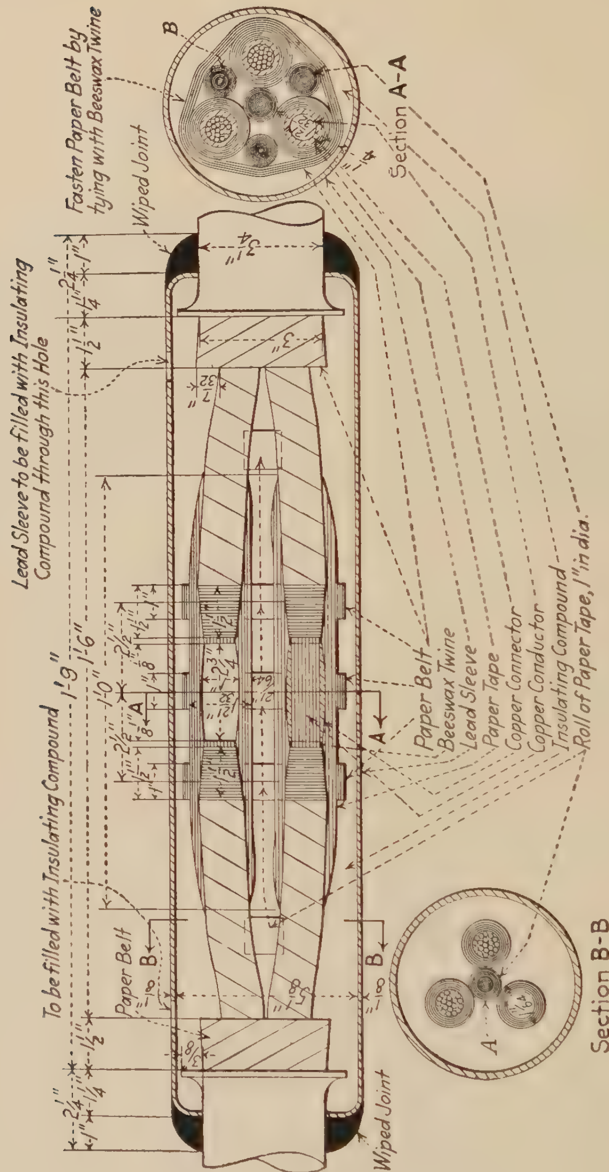


FIG. 172.—Drawing of 4,500 V.—4 conductor splice.

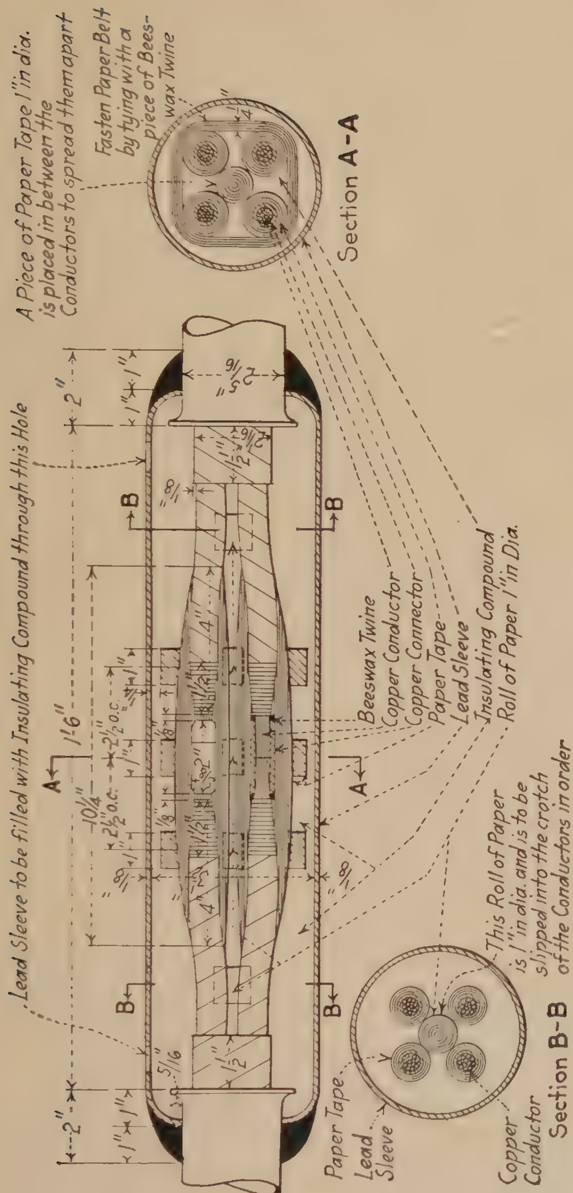


FIG. 173.—Drawing of 13,200 V.—3 conductor splice.

as the 13,200-volt splice, but not as much paper is used for insulation. Rack the cable around the manhole taking care to bend carefully and slowly. Saw off the cable so that the two ends will butt together, then mark off 9 in. from each end. With a chipping knife cut around the cable, then cut lengthwise as described for 13,200-volt splices. Bell the lead and remove the paper belt beginning from a point 1½ in. from the belled lead. Pencil the insulation on each conductor, tape over with cotton tape, tin the ends and sweat the copper connectors on. Wipe off smoothly with cotton tape and wrap waxed twine at each end of the connector filling up the small space that cannot be filled with paper. Then insulate each conductor with paper insulation to one and one-half times the thickness of the insulation on the cable. Use a 1-in. roll of paper at each end of the splice in the crotch and one in the center to hold the conductors apart. Then apply three belts as shown in Fig. 173. Boil out the splice with hot compound beginning at each end and working toward the center. The lead sleeve is then pulled over the splice, the ends dressed in and the joints wiped, after which the splice is filled with compound and sealed. A 3½-in. lead sleeve 20 in. long is used for this splice.

Specifications for Copper Connectors.—It is important to have the proper design of copper connector square. Sharp corners

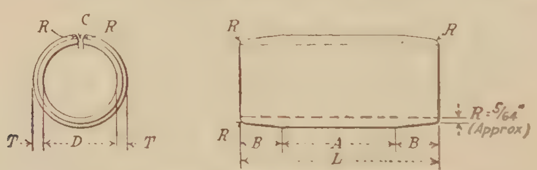


FIG. 174.—Specifications for copper connectors.

must be avoided. The beveled ends are the best as they are convenient to insulate and make a very good soldered joint. The heavy section is in the center (see Fig. 174), which gives the shape, dimensions, and a table, for the various connectors.

Cable Racks and Hangers.—There are many designs of racks and hangers on the market, which have their respective advantages. It is important to erect proper hangers for cable to rest upon and to have them placed as near as possible at equal spacing to prevent the cable sagging at the edge of ducts. If racks are used on the walls, they should be put up with ⅝- or ¾-in. expansion bolts. Care should be taken to see that the hangers

will be at the same elevation as the ducts, at least on one side. Figure 175 is a drawing for a cast-iron cable rack. The hangers which the cable rests upon should be generous in width, with round edges. No sharp edges on hangers are permitted. The round edge will allow the cable to slide over without cutting into the lead. Figure 176 is a cast-iron hanger, which fits into a rack,

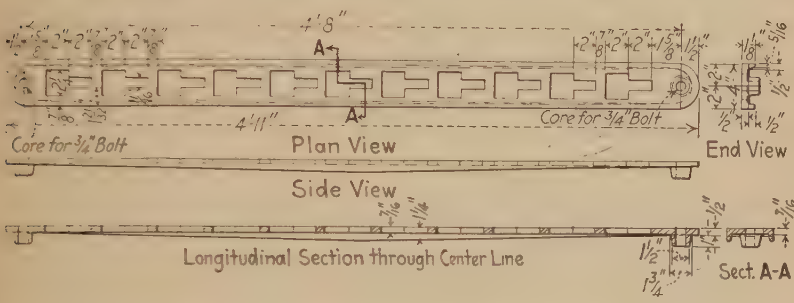


FIG. 175.—Cast iron rack for cable hangers.

as shown in Fig. 175. These hangers are made for one, two, and three cables and can be used for all sizes of cables up to 4/0, 13,200-volt, three-conductor cables. The hanger used for 400M, three-conductor 13,200-volt cable is shown in Fig. 177. This hanger is used without a rack and is made fast to the manhole wall with

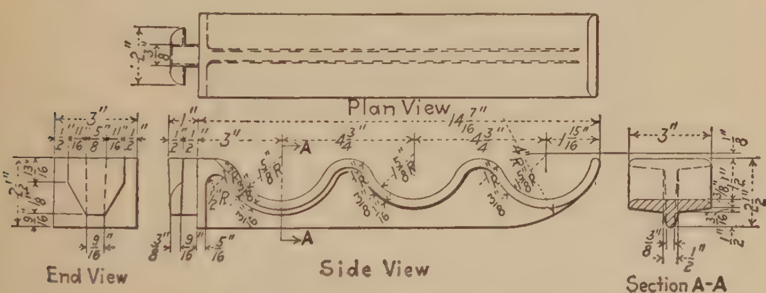


FIG. 176.—Cast iron cable hangers.

an expansion bolt. There are conditions, at times, that make it necessary to build deep manholes, due to obstructions, etc. In a case of this kind, the ducts enter the manhole at different elevations, thus causing a long drop of cable with a bend near the hanger. Figure 178 is a drawing for a cable guide or rest for a bend. This guide will fit into the hanger, as in Fig. 176, and

makes a very fine support for the cable bend. The guide is made of malleable iron.

The Branch Splice.—A branch splice on 13,200-volt transmission cables is often made in connection with feeders serving primary customers or where a new duct system connects to an old

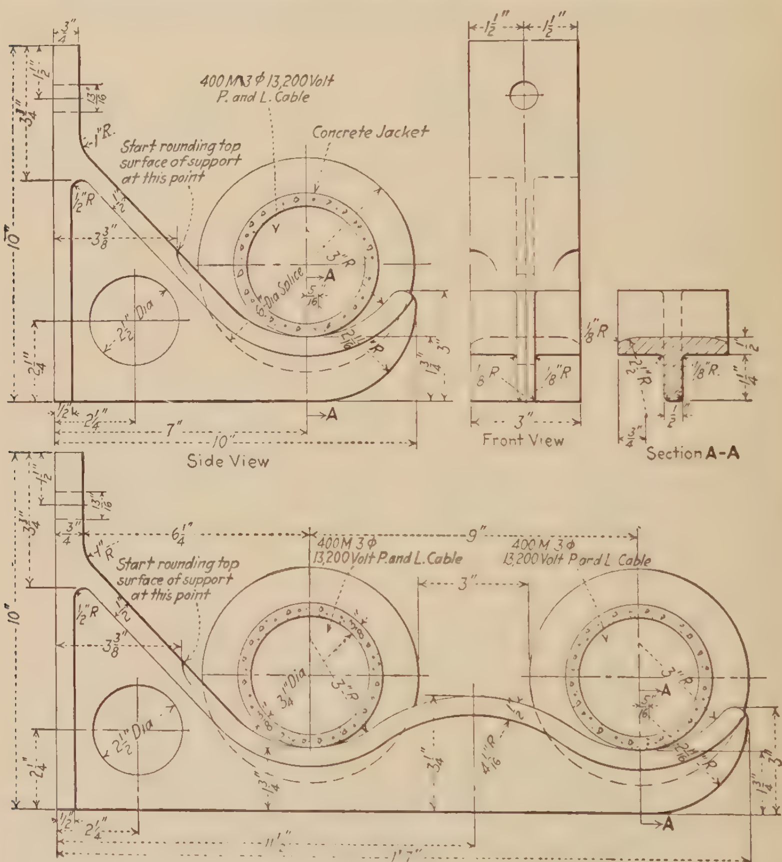


FIG. 177.—Cast iron cable hanger to be used without rack.

system. The new duct may allow the installation of a large cable while the old duct system would not be large enough for the large cable, so it is necessary to install two cables to equal the one large cable.

While the branch splice is practically the same as the straight splice, great care should be taken with it. The splice is necessarily larger and is more complicated. All the dimensions are

given in the drawing (Fig. 173). When racking the cable for a branch splice, bring the branch cable on top of the main cable. In this splice it will be noticed that the splicing connectors are on one end, or greater length is required on the branch end of the splice, as shown in Fig. 178*a*. The two 3/0 conductors are spliced to one 400M conductor, a 400M copper connector being used. The lead on the cable is removed as described in the straight splice, the paper insulation is removed and penciled, and wrapped with cotton tape. The copper connectors are sweated on and then wax twine is used to fill out at the ends of the copper connectors. Remove the cotton tape, clean the splice very carefully to

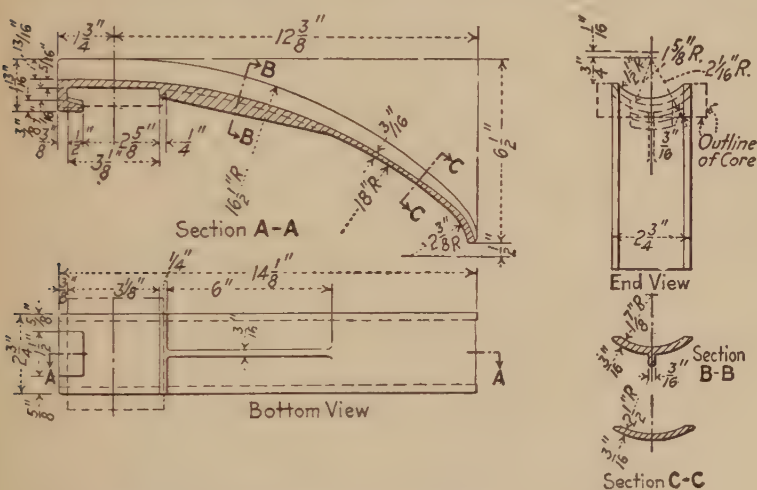


FIG. 178.—Malleable iron cable guide or rest for bend.

remove chips or small pieces of solder in the crotch. This is very important, as all metal parts must be smooth and free from sharp points or edges. Insulating is done with paper insulation, wrapping the copper connector first up to the level of the factory insulation on each conductor, then each layer should cover the conductors for a length at least 12 in., and, as each layer is advanced, insulation paper should be packed into the crotch using petrolatum with each layer and in the crotch. The crotch is a very vital point and great care should be taken with it to see that it is made solid and without voids. While making this splice, as with all three conductor splices, be careful not to bend the conductors more than necessary. That is one of the reasons

for making this splice so much longer. Place small rolls between conductors as shown. After the three conductors are insulated,

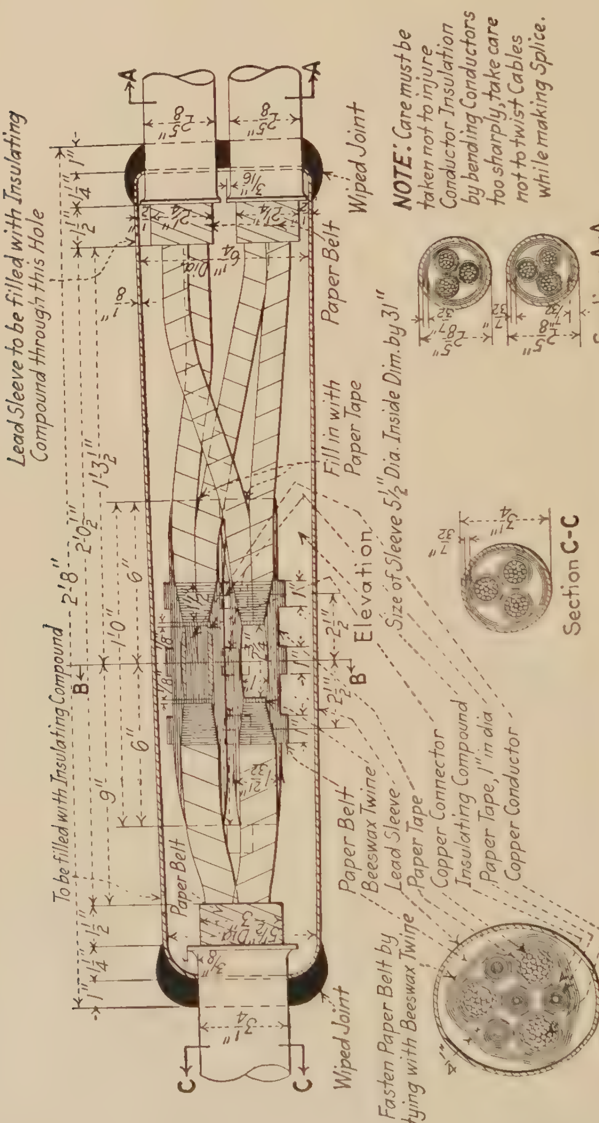


FIG. 178a.—Drawing of branch splice for 3 conductor, 13,200 volt paper insulated cable.

apply five belts of 8-mil paper on the splice as shown. Then boil out the splice with compound. A thermometer should be used to determine the proper temperature. Put the lead sleeve on, dress-

ing the straight end in first, then dress in the branch end. A standard cast-lead plug should be used at the branch end to prevent solder from working into the splice. This plug holds the two cables in place and if properly cleaned will make wiping easy. This method is better than driving pieces of lead sheathing into the crotch. Great care should be taken with the branch-wiped joint as it is a large joint and requires a large amount of solder, so that it is necessary to have a large pot holding at least 30 lb. of solder. While the operation of wiping is going on, care must be taken to tin the crotch and the lead plug thoroughly. The jointer must satisfy himself that this is done before he tries to wipe the joint to finish it. After both joints are wiped, fill with compound and keep the splice wrapped with a blanket while it is cooling. It will take considerable time for a splice of this size to fill properly. Allow at least 2 hr. for filling when using hard compound and cover with a blanket while cooling. When the final filling is accomplished, carefully seal filling holes with half-and-half solder. Before leaving this splice be sure that the branch cable is properly supported so that any one stepping on it by mistake would not break the lead near the wipe. Of course, in all well-regulated, underground systems, it is understood that cables are not racked in manholes for the purpose of climbing on them, yet this splice must be made foolproof.

Low-voltage cables, such as 110 to 600 volts, have their problems as well as the higher voltages. Just as much care must be taken when bending or racking cables. The insulation on these cables is light while the copper is usually heavy and stiff, and if the cable is bent too sharply the heavy copper causes the insulation to crack or tear, so a standard for bending this class of cable is as important as one for high-voltage cable. This standard should be at least 10 diameters of the cable. This is necessary not only for mechanical reasons but for electrical purposes. The low-voltage cable carrying the maximum load will run hot, and, when the off-peak comes, the cable suddenly cools off, causing great stresses on the lead, copper, and insulation due to unequal contraction. For this reason, it is necessary to make good bends and these bends should not be made near the duct but at least 12 in. from its face, leaving that much straight cable to slip into the duct during the high peak. That means that racks should be provided to keep the cable off the duct edge and protectors should be placed in the ducts under the cable. Figure 179 is a 1,000,000-

cir. mil cable splice for up to 600 volts. The cable is racked around the manhole on hangers and is cut to butt the ends together. A mark is made on each end 5 in. from the end. The lead is ringed with a chipping knife, the cable is then scraped clean and covered with stearine wax. The 5-in. section is now removed with the chipping knife, care being taken not to cut the insulation. The knife should be held at an angle to prevent cutting the insulation. Now cut 2 in. of insulation off of each end, scrape the ends of the conductor free from paper and compound which is dragged into ends and strands during the sawing operations, rub stearine wax over the copper ends thoroughly, then tin carefully by using two large ladles or holding a solder pot up to the ends. Judgment in this must be used where there is gas present in the manhole. This compound becomes fluid due to

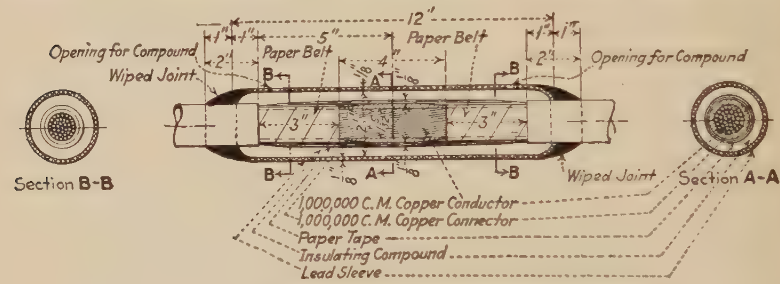


FIG. 179.—Drawing of 1.000,000 cir. mil cable splice.

the heat of the solder, and runs into the hot solder pot and may ignite the compound and cause an explosion. After the ends are tinned, a copper connector is placed over one end and the other end pushed into the connector. The two ends are pushed together and held while the copper sleeve is swedged together with a hammer and an anvil block held in one hand. The copper connector is then sweated with solder preferably half-and-half. It is best to have two solder pots, one for sweating and one for wiping. Solder should be poured over the connector until it runs freely through the copper cable, then allow the solder to cool slightly while pouring. Then take a large wiping cloth and wipe the connector clean and smooth. After this is done, apply the paper insulation, wrapping the paper from lead to lead. The splice is then boiled out, the sleeve is dressed on and wiped, and the splice is filled with compound. Single-conductor cables are usually hand wrapped and do not take much compound, there-

fore not much time is required for the splice to settle. The copper connector is 4 in. long and the lead sleeve is 2½ by 12 in.

The 1,500,000-cir. mil and 2,000,000-cir. mil cable splices are made in a like manner with the exception of the length of splice and size of sleeves. The length of the 1,500,000-cir. mil splice is 15 in. and the lead sleeve is 14 in. long, and the 2,000,000-cir. mil splice is 16 in. long and the lead sleeve is 15 in.

The branch splice for single-conductor, 600-volt cable is made in the same manner as the straight splice only that a branch connector is used and two cables are at one end as shown in Fig. 180. The ends must be thoroughly tinned. The branch cable is prepared

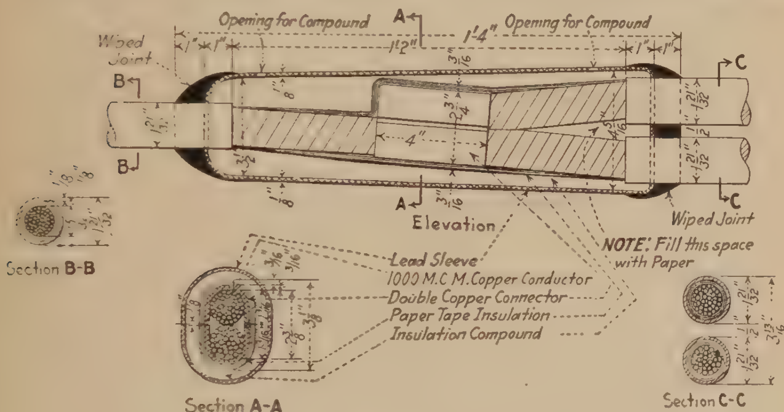


FIG. 180.—Drawing of 1,000,000 cir. mil branch cable splice.

to go through the connector. The sleeve is swedged together as in the straight splice. The branch cable should be placed on top of the main cable. This makes good racking in manholes. There is no serious objection, however, to bringing the branch cable to the side of the main cable. When sweating the branch splice care must be taken to get a good solid connection. When insulating the branch splice run the paper over the end of the connector where only one cable comes out, and bend or fold the paper over the end so that it will be insulated. Place paper in the crotch after the splice is insulated, boil out, and put the lead sleeve on. Dress in the straight end first, then dress in the branch end, using a cast-lead plug in the crotch, after which wipe and fill. The question is often asked, is it best to wipe the crotch with a finger cloth or to cut the crotch with a knife or to wipe? All three methods are being used successfully and if the crotch is

well tinned there is no reason why one should not be as good as another. In wiping joints, the most important thing is to tin the joints all over before trying to make the finished wipe, and do not do this until you have the proper heat. Another point is to make the wipe joint long enough. Short joints do not give enough surface to work on and the danger is not to get the cable and sleeve properly tinned. This will allow water to leak into splice and then the trouble begins. All joints should be at least 2 in. long and on large joints or branches they can be made longer. Always cut two holes in the sleeve when filling with compound and allow compound to flow through the splice.

A splice used a great deal in Edison systems where 500,000-cir. mil, three-conductor cables are used for mains is the three-way splice as shown in Fig. 181. The three single conductors are connected to the bus bars in the junction boxes. The same methods are used as explained for other splices. The three single cables are connected to the three conductors of the three-conductor cable. When setting up this splice, however, it is always best to have one of the single conductors in the bottom of the splice. It makes the best position for wiping.

Another splice used on Edison systems where 500,000-cir. mil cable is used for mains is the branch splice for customer service as shown in Fig. 182. This splice is made where two services are taken off at one point or handhole. The splice is usually made about 21 in. long depending upon the space or the size of the handhole. This splice is usually made while the main is in service, which means that the splicer works on live cables in a small space. Great care must be taken, therefore, to prevent grounding or short-circuiting while working on the splice, which will not only cause the dropping of a number of customers from the system but burn or otherwise injure the splicer. It will be noted that no copper connectors are used on this splice. The connectors make too bulky a splice so the splice is made by bringing the conductors together and binding with copper wire and then sweating all together with solder. Only one conductor should be uncovered at one time. If it is necessary to have more than one, keep them separated with a rubber blanket. A rubber blanket should be used on the sides of the handhole where the splicer is likely to come in contact with the handhole, casting, etc. When wrapping the No. 18 soft copper around the conductor, the wire should be wound on a wooden spool or stick and no free end of wire

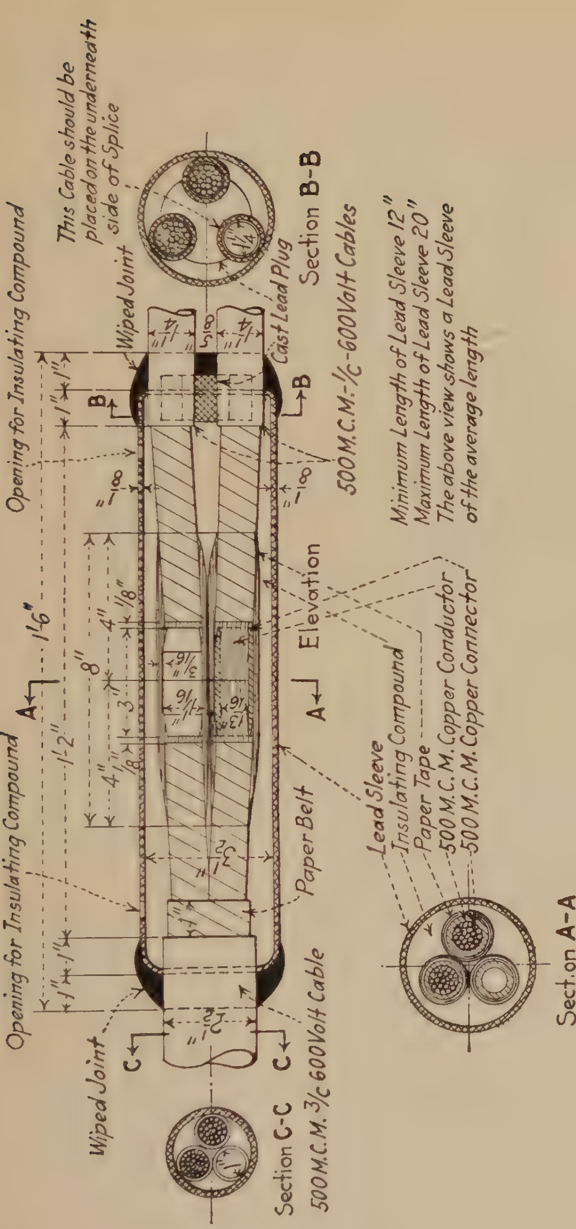


Fig. 181.—Drawing of 500,000 cir. mil three way cable splice.

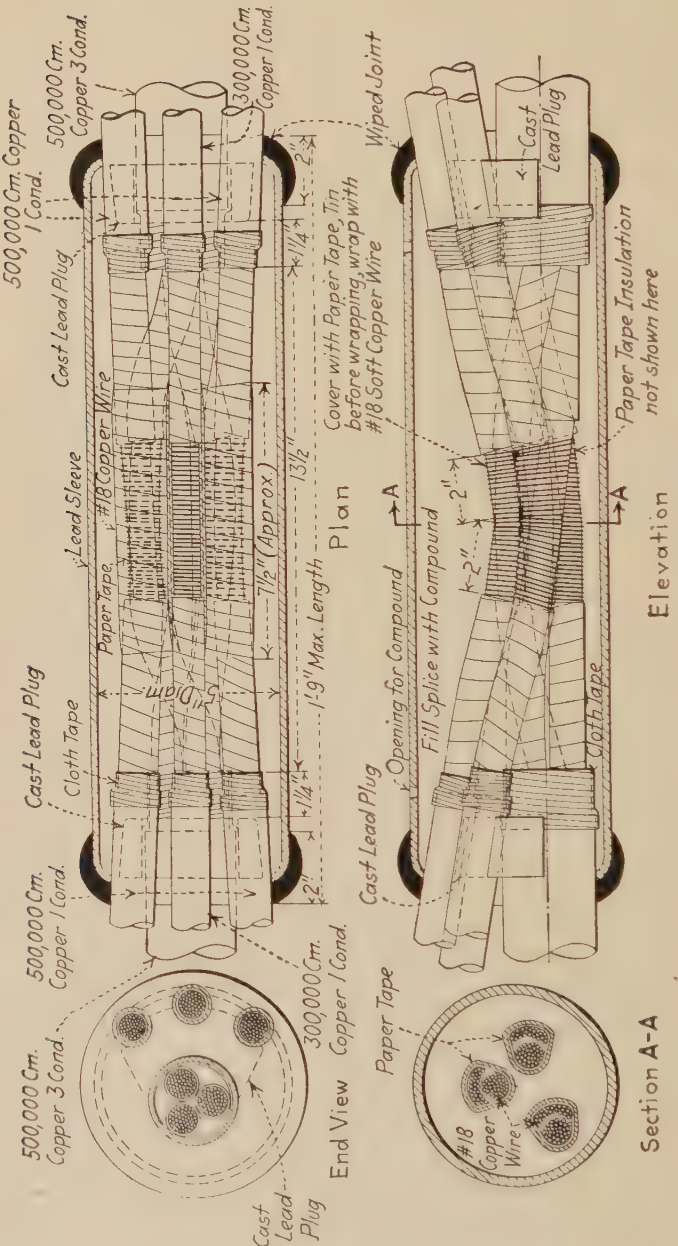
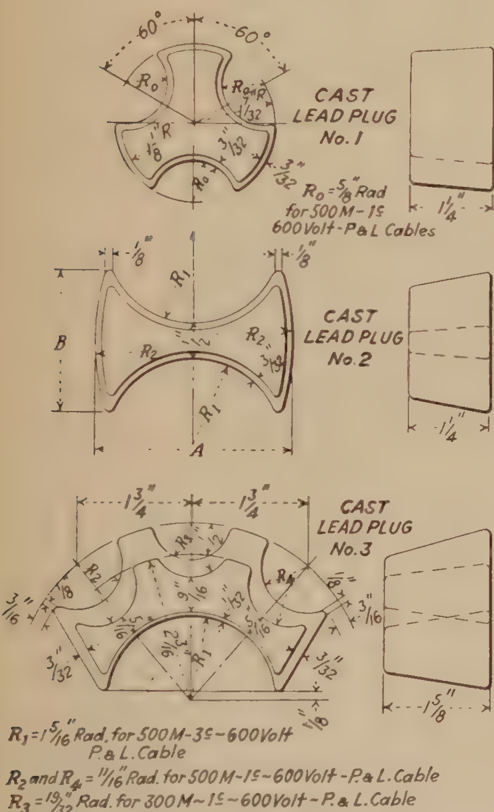


FIG. 182.—Drawing of 500,000 cir. mil service branch.

be allowed to pull out and come in contact with other cables during this process or there is likely to be a flash which would cause painful injuries. This is very important when working on live cables. It is best when doing this work to wear amber glasses to protect the eyes should a flash occur. It is always best to tape over the lead near the splice with friction tape. This splice is



DIMENSIONS FOR LEAD PLUG No 2

KIND OF CABLE	A	B	R_1	R_2
3c-400M-13 2 KV	$3\frac{7}{16}''$	$2\frac{3}{4}''$	$1\frac{5}{8}''$	$8\frac{13}{16}''$
3c-3o-13 2 KV	$2\frac{15}{16}''$	$2\frac{3}{16}''$	$1\frac{5}{16}''$	$4\frac{1}{16}''$
1c-1000M-600 Volt	$1\frac{3}{4}''$	$1\frac{1}{2}''$	$\frac{27}{32}''$	$4\frac{3}{8}''$

FIG. 183.—Cast lead plug is used to close opening between cables of branch splice.

insulated with varnished-cloth tape which is tough and will stand rough usage and is good for this type of splice. After all the branch splices are made and insulated, boil out with compound. Now put the lead sleeve on. Cast-lead plugs are placed in each end of the splice. The lead sleeve should be dressed down to them. They are well scraped on the outer surface and covered

with stearine wax. This plug tins very easily and makes wiping a large joint like this simple compared with the old method of driving pieces of lead cut from cable into the crotch. Such pieces never fit, and they allow solder to enter the splice. Using this cast plug has proved a very satisfactory method. It holds the cable in place as well. This plug is shown in detail in Fig. 183.

The Standard Underground Cable Company's Joint.—In making the standard paper-tube joint, there is no difference in the preparation of conductors, lead sleeve, soldering the connectors, etc.; but after the connectors are soldered, fill the space between the end of the copper connector and the conductor insulation on each side with loosely woven and easily impregnated cotton tape. Apply similar tape in one layer over the copper connector for its entire length. Boil out the tape and adjacent cable ends carefully with compound. As the tape must have its moisture boiled out in case any is present and be thoroughly impregnated besides, nothing but very hot compound will suffice.

Placing Tubes in Position.—After all the conductors have thus been joined, place each of the small jointing tubes so as to cover the joint on the conductor completely. The proper position of the jointing tube is such that the middle of the tube is over the middle of the copper connector, or so the tube equally overlaps its original conductor insulation at each end. Secure the tubes in position by means of flax twine stretched tight over each and tied at each end to the conductor.

Place the enclosing or large jointing tube over the smaller tubes so that its middle point is over the middle points, and bind it in this position with flax twine as in the case of the small tubes. Do not put wrappings of any sort —either paper linen or rubber—over the tubes, as this prevents the filling compound entering the spaces between tubes and conductor and between the inner and outer tubes, which entrance is absolutely essential to complete success in a joint of this type. The lead sleeve is now wiped on the cable. Cut two holes in the sleeve. The holes should be placed near the end of the joint so that the stream of hot compound will strike the belt insulation of the jointed cable. Before pouring in the hot compound, the joint should be tilted so that one end will be slightly higher than the other, as it is necessary to pour the hot insulating compound into the hole at the lower end of the joint. An iron filling cup, one end of which is belled out to

make a funnel, should be screwed into the filling hole at the lower end of the joint. This cup or funnel must be long enough to bring its top on a higher level than the overflow hole in the other end of the sleeve when the joint is in the inclined position. Note that the object in placing the joint in this inclined position and pouring the compound into the lower end is to drive all air and moisture upward in the natural direction and away from the soldered joints, the hand-applied insulating tape, and the tubes.

The ozite insulating compound having been heated to the pouring temperature indicated on the table on the container which temperature should be determined by a thermometer), it should be poured slowly and steadily into the filling funnel at the lower end of the sleeve. At least 2 or 3 gal. of compound should be

Fig. 184.—The Standard Underground Cable Company's joint. (Above.)
Fig. 185.—The large jointing tube in place. (Below.)

allowed to flow through the overflow hole or until the portion overflowing is entirely free from bubbles.

The joint should now be allowed to settle for at least 4 or 5 hr. until cold, covered with a canvas pad, oilcloth, or other protection from cold air, dirt, moisture, etc., and to prevent chilling too rapidly. When the joint has cooled sufficiently to prevent cracking of the soldered wipe, the lower end should be raised so that the joint is level for further settling and the joint placed in its permanent racked position. The joint having thoroughly settled and cooled, refill it through the same filling hole as before so as to fill up all air spaces due to shrinkage in the original filling. Solder up the filling holes and the joint is complete. Figure 184 shows the conductor tubes in place. Figure 185 shows the large jointing tube tied in place.

The Conducell Splice.—The Conducell method of insulating joints is as follows: After the single conductors have been properly soldered together they are wrapped with black varnished-cambric insulating tape soaked in a compound used for filling and laid up

in successive layers to the thickness of the original insulation at the point where this has been removed from the conductor. Then a factory-formed insulation that only requires mechanical assembling between and around the single conductor is placed in position, thus leaving the workman no choice as to the proper construction. Conducell insulators are made of an insulating material known as "Micanite," for two-, three, and four-conductor cables in sizes and thicknesses to suit all transmission cable requirements. Conducell for three-conductor cable consists of an outer seamless tube and three similarly formed curved inner separating pieces. It will be noted that the several parts when

FIG. 186.—The Conducell splice showing the three sections of Conducell held in place by the porcelain spacing pieces.

assembled will form three separate cells for the conductors, that the insulating parts are interlocked among themselves, and that when assembled in place in the joint the Conducell as a whole is held in a positive relation with reference to the conductor by means of spacing pieces. This spacing insures the same separation and amount of insulating compound between each of the three conductors and at the same time maintains a fixed and definite relation between all the component parts of the joint with reference to the lead sleeve. Figure 186 shows the three sections of the Conducell held in place by the porcelain spacing pieces, ready for the outer tube to be drawn over. A special filling nipple, which is made part of the lead sleeve is used for this joint. The joint is filled with compound in the regular manner, a quantity of compound being run between the two filling holes to remove all surface bubbles, etc. The unnippled hole is then sealed as usual, and a pressure test is made on the joint by forcing compound into the nipple by means of a pressure gun. This gun develops a pressure of 60 lb. or more per square

inch which detects any pin holes or weak spots. While the pressure is on, as shown in Fig. 187, this nipple permits the joint to be sealed without delay. The inner plug is screwed down through the filling head without releasing the pressure. Joints filled in the manner described will not leak at joints or seals. It has been found that the more fluid oils tend to run into the cable, creating an underpressure or vacuum in the joint. If any pinholes occur in the seal or wipe, air or water will be drawn into the joint. If the joint is tight, however, no such displacement can take place.

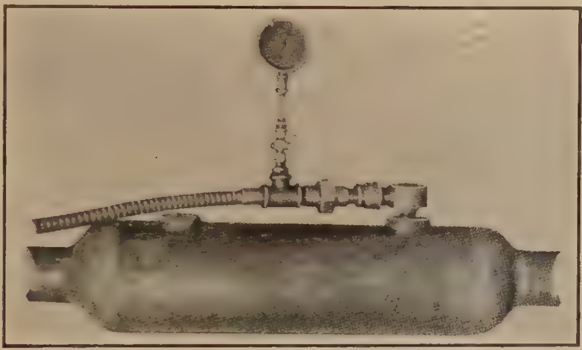


Fig. 187.—Shows the method of filling.

The Superior Cable Joint.—Instructions for making joints on 350,000-cir. mil, three-conductor, 33,000-volt sector cable cell type: After the general instructions for making high-tension joints have been completed, the general procedure for making the above joint is as follows:

Finding the Trial and True Center of the Joint.—Select a point where the two ends overlap, for a trial center. Remove the lead sheath and belt paper from each cable to a point approximately 4 in. beyond this trial center and then with the conductors thus exposed, select a point for the true center of the joint where the conductors of each end of the cable can be brought into such a position that the three copper sleeves will be in a triangular position with the apex up. This brings the copper sleeves into the best position for soldering and for their final position in the completed joint. The cable is not to be twisted to bring the conductors into the correct position. There shall be 26 in. of straight cable on each side of the center, which will allow 6 in. of straight cable outside of the 2-in. wipe.

Removing Lead Sheath from Cables.—Measure 13 in. and 16-in. back from the true center of the joint on each cable end, mark the lead sheath, and then with a sharp chipping knife cut grooves, nearly, but not quite, through the lead around each cable end at each mark. Scrape the lead sheath and grease it with a candle for a distance of 4 in. back from the 16-in. mark. Make a longitudinal cut in the section of lead between the 13-in. groove and the end of the cable and then remove this piece by tearing it off at the cut around the cable. Remove the belt and filler insulations to the end of the lead and wrap each conductor with one layer of impregnated cheesecloth.

Preparation of Lead Sleeve.—Use the two-piece sleeve which has been previously prepared, carefully removing all dents and adjusting the seams with a lead dresser. Scrape the outside surface of the lead sleeve for a distance of 4 in. from the end and 2 in. from the center of the seams, after which cover the entire scraped portion with lamp black. When the lamp black has dried, scrape off 2½ in. from the ends and 1 in. from the center of the seams and cover the scraped portion with candle grease.

Placing of Outer Tube.—Wrap a piece of impregnated cloth around the sheath of the cable, and one end to cover the lead for a distance of approximately 24 in. Slip the outer insulating tube over the protected end of the cable using extreme care that the inside of the tube does not touch the bare lead. This care is necessary because a lead mark on the surface of the insulator tube will tend to form a conducting path from the copper conductor to the lead sheath and cause the joint to break down. Cover the outer insulating sleeve with impregnated cloth.

Preparing the Conductor Ends.—Cut off the three conductors' ends squarely at a point 13 in. from the cut lead. Remove the conductor insulation for a distance of 2½ in. from the conductor ends cutting the paper at right angles to the coppers. Tie a string binder around the paper of each conductor at a point 3 in. from the insulation edge to prevent the paper from loosening. Crush the sector-shaped conductors round with smooth gas pliers and bind with No. 13 iron wire at the ends of the coppers to hold them in this cylindrical shape. Apply soldering paste to the coppers.

Soldering Conductor Ends in Copper Sleeves.—The conductors are inserted in the copper sleeves which have been previously tinned, at the same time removing the iron wire, leaving a gap of

not more than $\frac{3}{16}$ in. between conductor ends, and with this gap exactly at the center of the sleeve. Apply more soldering paste and then pour hot string solder over and through each sleeve until the copper sleeves and the ends of the conductors adjacent are heated to the proper soldering temperature. The solder should penetrate between the strands of the conductors, displacing the cable compound, and also be allowed to collect and cool slightly so that a surplus can be built up along the slot and over the ends of the sleeve. After this operation is completed on the three conductors, smooth off the excess solder on the copper sleeve with a $\frac{1}{2}$-in. flat file and finish with an abrasive strip of sand paper, so as to leave an absolutely smooth joint tapered down to the coppers and with no sharp edges.

Tapering Conductor Ends and Applying Tape.—After completing the soldering operation, the work of penciling the conductor insulation and applying the hand-wrapped tape on the first conductor should be completed before starting the second. The insulation on the remaining conductors being left full length and covered with clean impregnated cloth until each is worked on. Tie a string around the conductor insulation at each end, $1\frac{1}{2}$ in. from the end of the solder, and then taper the insulation down to the copper over a length of 1 in. using a very sharp knife and making a smooth surface with no ridges or depressions. It is very important that this operation be performed as carefully as possible, as this is the weakest point in the joint. As soon as the penciling has been completed on each end of each conductor, the cut surface shall be painted with warm S. T. A. oil to exclude air. Then remove the outer layer of conductor insulation on each end to a point 3 in. from the cut end. This is done to remove any moisture, dirt, or metallic filings which may have entered the paper and to provide a clean surface for the application of the tape.

The rolls of tape are to be taken from the can one at a time just before each is applied. One hundred feet of $\frac{3}{8}$-in. by 5-mil. paper tape half-lapped is to be applied between the penciling of conductor insulations with one continuous layer extending over the copper sleeve. Two hundred feet of $\frac{3}{4}$-in. by 5-mil. paper tape is to be wrapped, half-lapped, over the $\frac{3}{8}$-in. tape for a distance of 17 in. The overall diameter should be $1\frac{9}{16}$ in. for 15 in., gradually taping down to the conductor insulation completing the 17 in. of taping. Hot S. T. A. oil is to be painted on every

layer and the tape is to be applied smoothly, evenly, and tightly, eliminating all air pockets between layers. The penciling and taping operation is then to be repeated on the second and third conductors in turn. After all three have been insulated, the remaining portion of the first layer of paper on each conductor is to be removed to a point near the crotch. At this point the joint should be thoroughly boiled out with S. T. A. oil.

Assembling Insulators.—Assemble the conductor tubes with the slots in the two coinciding. Insert the assembled tube separators over each conductor and rotate them so that the slots of the outer separating tubes are faced out from the center of the joint and the slots on the inner tubes are toward the center of the joint. These separators are to be centered in the joint by so placing them that the distance between the end of the separators and the end of the lead is the same at both ends. It is very important that extreme care be used in the process of inserting and centering the separators to avoid damage to the insulation.

Removing Remainder of Lead and Belling.—After the conductor insulators are assembled, remove the 3 in. of lead from each cable between the 13-in. and 16-in. groove by tearing off to bell the lead. Complete the belling with the belling tool, raising the edge of the lead 3/8 in. away from the belt paper, using care not to injure the insulation. Slide the outer insulating tube in place and center it with the joint by so placing it that the distance between the end of the insulating tube and the end of the lead is the same at both ends. Assemble the two corrugated fiber spacers, 2 in. from each end of the outer tube. Make the final boil-out over the outer tube and insulators to remove any possible moisture that may have collected during the handling.

Wiping Lead Sleeve.—Make a mark on the lead sheath of each cable end at a distance of 1 1/2 in. from the belled end. These marks are to be used for centering the lead sleeve. Hold the lower half of the sleeve under the joint and carefully fit the top half in place, binding it temporarily with two pieces of No. 13 iron wire. Adjust the seams to make a tight fit and wipe with wiping solder and a blow torch. Beat the sleeve ends tightly to the cable sheath and proceed to wipe in the usual manner.

Filling the Joint.—Have the compound tank filled to a point 2 in., from the top and the S. T. A. oil heated to a temperature of 125°C. Attach the filling hose to the tank, open the valve

on the tank, allow at least 1 qt. of compound to flow through the hose into a can, close the lower valve, and then, before the compound in the hose can become too cool to flow, attach the hose to the joint with the extension hose reaching to the bottom of the joint. Allow oil to flow into the joint until it overflows and until all frothing has ceased. At least 2 gal. are to be poured through at a temperature of 110°C. The first quart which overflows is to be thrown away and the rest is to be caught in a clean pan for reuse. The filling holes are to be covered loosely, and the joint allowed to stand for at least $2\frac{1}{2}$ hr. before sealing. The compound level is then to be checked and should be $1\frac{1}{16}$ in. over the top of the outer insulating tube.

The leather gasket and the threads in the cap are to be coated with shellac and screwed tightly on the nipple. Figure 188 shows this splice.

FIG. 188.—The Superior cable joint.

The Cleveland Cable Splice.—The design and construction of the Cleveland type of splice show many radical departures from other joints heretofore used. Use is made of a combination of a wrapping of impregnated paper tape and a shellacked-paper tube. This type combines many of the advantages and eliminates some of the disadvantages of each type of insulation used separately. In starting the joint, the lead and paper of the cable are removed by a square cut which exposes about $\frac{3}{4}$ in. of the conductor. By the use of a special cutting tool designed for this purpose the paper insulation is then undercut at an angle of 15 deg. from the axis of the cable, leaving a conical space next to the conductor. How this work is done is shown in Fig. 189.

Special Connector Used.—A thin brass shell made in the form of a truncated cone is next placed in each cavity. This shell is made in the exact form of the sloping paper surface, having holes provided for use later in sweating the connector and filling the shell with solder. The conductor ends are inserted in the ends of an ordinary copper connector. The two cable ends to be formed

are then crowded together by the use of a geared device designed and built for this purpose, illustrated in Fig. 190. This opera-

FIG. 189.—The Cleveland cable splice undercutting the paper insulation.

FIG. 190.—Sweating connector and forcing ends together.

tion brings the cable ends together in true alignment, fitting the ends of the brass shells closely. By pressing the shells tightly

against the sloping paper surfaces no air is entrapped between the brass surface and the paper insulation. The copper connector is then sweated at a high temperature and the entire conical space within the cones is filled with solder at a lower temperature.

On account of the short truncated form of the conical brass shell a portion of the solder comes in direct contact with the paper insulation. It was found that the hot solder can be poured against the paper with no undesirable effects, while the use of a full conical shell was found to introduce difficulties due to entrapped air. This results in a metallic connector for the conductor, which has the same diameter as the factory-made insulations of the cable and has no sharp corners. As will be pointed out later, this reduces the stress on the surrounding insulation at this point. The lead armor is then removed for a distance of 18½ in. from each side of the center of the joint. A winding of impregnated paper tape extending for 12 in. each way from the center is then applied to a thickness of ¾ in. in the central 13 in. and tapering to the cable insulation at the ends. The appearance of the joint at this stage is shown in Fig. 191.

The tape is machine wrapped. This machine is built in such a way that it can be easily operated in a standard manhole and can work within a space of 6 in. between the cable and the wall. It also permits application of compound over the successive layers of tape at a temperature above the boiling point of water. Over this is slipped a shellacked-paper tube large enough to allow a space of ⅜ in. between tape wrapping and tube. This is held rigidly in place by spacers placed between the tube and the tape wrapping. It is also centered in the outer sleeve by spacers cut from the same diameter tube as shown in Fig. 192.

The outer sleeve of the joint is constructed of brass and is 8 in. in diameter at the center. It is made in two sections, which telescope together at the center, one being slipped over each end of the cable before any jointing work is done. Experiments at voltages more than five times normal showed excessive stress on the insulating compound in the angle where this sleeve joins the cable sheath. This difficulty is overcome by filling this space with a wrapping of cotton candle wicking which has been previously impregnated by a vacuum treatment. In order to secure intimate contact between this candle wicking and the metal surfaces, the lead of the cable armor is slightly belled and the candle wicking forced under it. The filling compound used in this joint

is thinned petrolatum. This is poured into the joint at a temperature of 240°F. and allowed to run through and out a second opening at the top of the sleeve until all traces of air and mois-

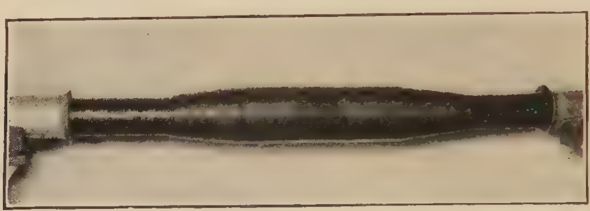


Fig. 191.—The appearance of joint after insulating.

ture have disappeared. One of the filling openings is then closed with a hermetically sealed, expansible and contractible reservoir, and compound under pressure is applied to the other opening for

Fig. 192.—Showing wrapping on each end and spacers.

a period of approximately 18 hr. This reservoir, made of soft brass, is shown in Fig. 193. The corrugations of this reservoir permit expansion and contraction sufficient to care for the

Fig. 193.—Showing Cleveland splice complete.

changes in volume of the compound in the joint as it passes through temperature cycles in operation and to prevent vacuum voids in the cable. The complete details of the joint are found

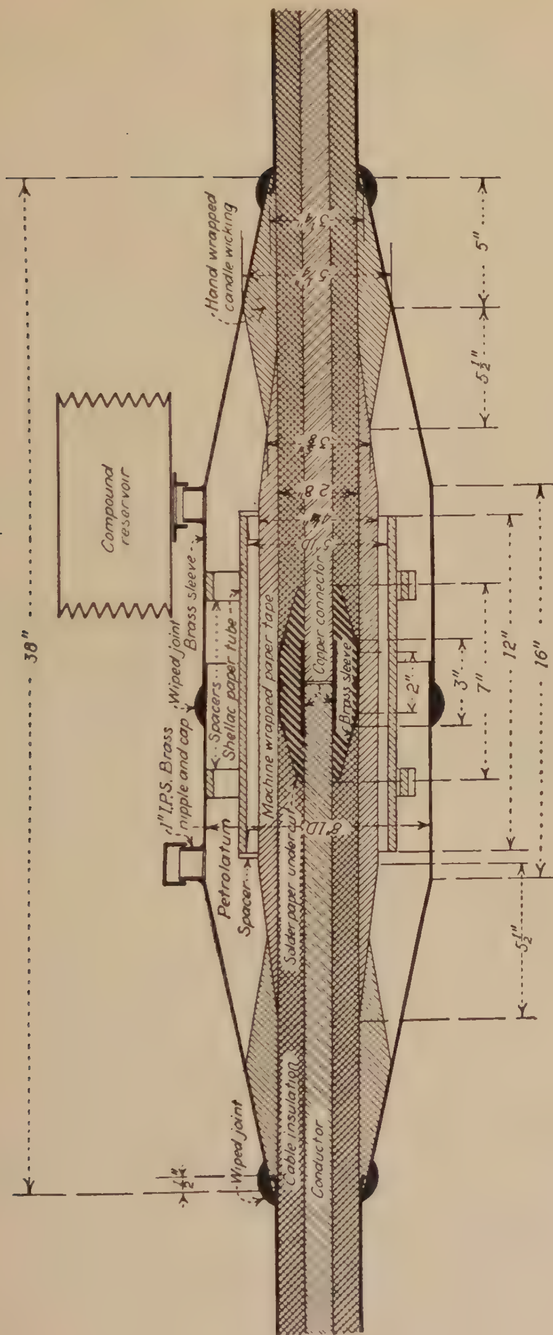


FIG. 194.—Complete detail drawing of the Cleveland splice.

in Fig. 194. It is built up by the machine shown in Fig. 195, which is small enough to operate in a standard manhole.

Materials Used.—Paper tape, and manila rope paper are used, 6¾ to 8 mils thick, 1 1/16 to ¾ in. wide. The paper is vacuum treated and saturated with vacuum-dried petrolatum or a mixture of 40 per cent petrolatum and 60 per cent No. 10 transil oil. Paper is packed in saturating compound. Cotton candle wicking, "Old Kentucky Wick," 16 strands, vacuum treated and saturated with a mixture of 40 per cent petrolatum and 60 per

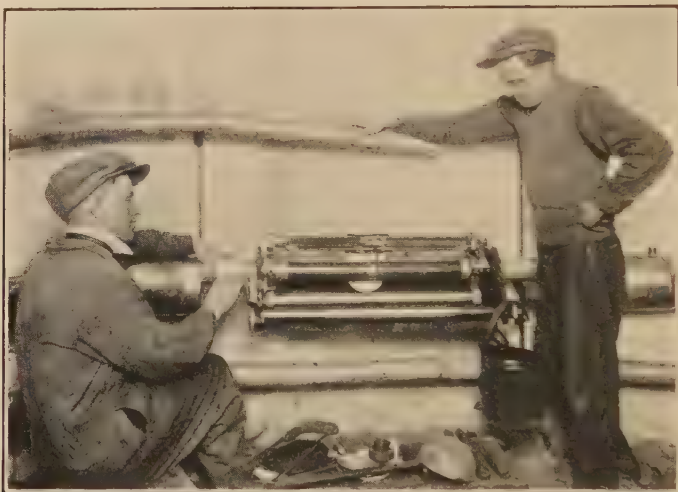


FIG. 195.—Insulating machine used for Cleveland splice.

cent No. 10 transil oil. Taping compound 40 per cent petrolatum and 60 per cent transil oil.

Filling Compound.—Same as taping compound. Insulating tube shellacked paper ¼-in. wall, 5-in. inside diameter, 12 in. long. Spacers same material as tube.

Connectors.—Seamless copper tube for inside connector. Inside connector is tinned. Outside connector sleeves are 20-gage commercial brass.

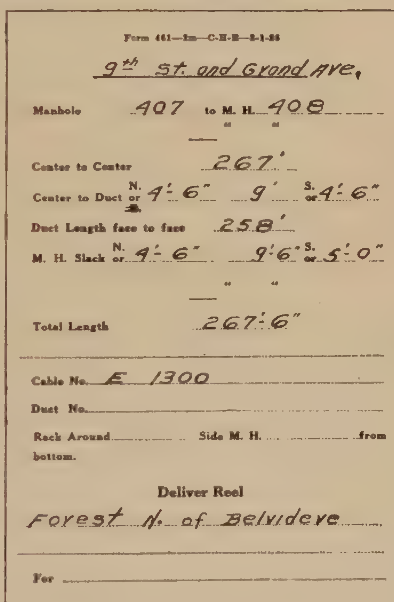
Brass Sleeve.—Eight-inch diameter sleeve, 20-gage commercial brazing brass, each end of sleeve is tinned for 3 in. from end.

Reservoirs, annealed red brass, soft enough to expand or contract under atmospheric pressure.

CHAPTER XI

RECORDS OF UNDERGROUND-CABLE SYSTEM

After the underground system is constructed, the cable installed, spliced, and put into operation, it is necessary to keep records of each length installed, so that when a length is removed for breakdown a history of the cable may be had. This record is especially needed when the cable has been installed by contract and under a 3- or 5-year guarantee. The record will show the date installed, the manufacturer's name, the date when put into operation, the name of the foreman installing cable, name of the splicer, etc. To explain the system of cable records, however, the matter will be taken up from the beginning.



Form 461—[illegible]

9th St. and Grand Ave.

Manhole 407 to M. H. 408

Center to Center 267'

Center to Duct N. or S. 4'-6" 9' S. or 4'-6"

Duct Length face to face 258'

M. H. Slack N. or 4'-6" 9'-6" S. or 5'-0"

Total Length 267'-6"

Cable No. E 1300

Duct No.

Rack Around Side M. H. from bottom.

Deliver Reel

Forest N. of Belvidere

For

FIG. 196.—Sheet from loose leaf book for cutting lengths.

Suppose it has been determined that a feeder or circuit is to be installed from the power house to a substation or from a substation to an overhead distribution or a customer, whatever the case may be. Maps and duct diagrams show the number of ducts in each manhole, the ducts occupied by cables, and the vacant ducts along the route where the cable is to be installed. It will not be possible to lay out the racking space or location in manhole at the office. This must be done in the field and by an experienced cable man who understands how cables should be racked to avoid short bends and crosses in cables and as far as possible to keep the high-voltage cables away from the cables

carrying high amperages where both classes of cables are in the same manhole. This is usually determined when the cutting lengths are measured. Figure 196 is a sheet from a loose-leaf book which is used by the man taking measurements for the cable. On the first line is entered the street location on which the cable is to be installed; on the next line manhole numbers; on the next line the center-to-center measurements between two manholes; the next line is the measurement taken from the center of the manhole to the face of the duct. In the north end of manhole 407 the measurement is 4½ ft.; and in the south end of manhole 408 the measurement is 4½ ft. The total is 9 ft. This is added to the measurement from the face of the duct in manhole 407 to the face of the duct in manhole 408 giving a total of 258 ft. The next line gives the length around the manhole wall or slack, the total in this case being 9 ft. The next line gives the total length of cable required. In the first place, there are 267 ft.; then 9 ft. are subtracted, leaving 258 ft. There are 9½ ft. for slack. This added to 258 ft. equals 267½ ft. total, which is the cutting length to be sent the manufacturer. The next line is the cable number and the next the duct number. The next line gives directions for racking and location on the wall of the manhole. This is important so that the foreman who installs the cable will know where the cable is to rack. If he were to rack it in another location it might not be long enough. The next line gives the location of the reel for delivery. After the cutting lengths are taken they are checked in the under-ground-department office and a recapitulation made from them giving cable number, manhole number, length of cable and location. This recapitulation is sent to the manufacturer.

Cable-record Cards.—As soon as the cutting lengths are sent to the manufacturer, complete information is put on the cable card (Fig. 197). In the right-hand column are placed the kind of cable, size, length, manufacturer's name, ordered for, purchase order number and date, date shipped, date received, manufacturer's reel number, and company reel number. The first line that runs across the card marked "location" shows the street on which the cable is to be installed. The first column on the left shows the cable number, distance from manhole to manhole, date drawn in and foreman's initials, date spliced, splicer's name, condition of cable, kind of duct, daily-report number, length of cable in manhole after splicing, and amount of cable cut off.

The next division is used if the cable fails and gives the trouble report number, date drawn out and destination, length returned to stock after testing or scrapped. This card is put in the stock

KANSAS CITY POWER & LIGHT CO.
CABLE CARD

UNDERGROUND DEPT. NO. 701

Location	Forest N of Belvidere - Lydia N. of 4th				
Used For Cable No.	E1300	P1321			Kind 13200 V
From M. H.	407	400			Size 3/0 3 C
To M H.	408	401			Length 266' 267' 270' 272'
Drawn In	1-1-25	3-3-26			Maker Standard
Spliced	1-4-25	3-7-26			Ordered For
Splicer	Crockett	Gooding			Stock
Condition of Cable	New	Sec. Hd.			P.O. 75400 Ordered 2-1-24
Kind of Duct	Tile	Tile			Shipped 12-1-24
Daily Report No.	1692	1861			Rec'd 12-7-24
Length in M .H.	1' 8 JK 2' S 1' N	10' 7' JK 1' S			Mak's Reel No.
Trouble Report No.					14672
Drawn Out	7-3-25 Report #1746				The K C P L Reel No.
Destination	19th & Campbell				4838 270' 6348 272'
270' on Reel 4838					

FIG. 197.—Cable record card.

list and, if used again, an entry is made in the second left-hand column as shown, so that a complete history is had of this piece

Work Order 6501

KANSAS CITY LIGHT AND POWER COMPANY
Foreman's Daily Report
UNDERGROUND DEPARTMENT

Report No. 1692 Jan 1 1925

Pulled OUT Cable No. ______ on ______ from ______ to ______

Length of good cable left ______ ft. ______ on Reel No. ______ Stored at ______

Length of junk ______ ft. ______ lbs. ______ Description ______

Remarks: ______

Kind of work ______ Credit to ______

Pulled IN Cable No. E1300 on Forest from M.H. 407 to M.H. 408

Length pulled in 272 ft. from Reel No. 6348 (—— ft.) taken from Stock

Length of good cable left —— ft. on Reel No. —— Stored at ——

Length of junk —— Make Standard Description 3/0 - 3 con. 13200 Volt

Remarks: New Cable Mfg. Reel # 14672

Kind of work Construction Charge to ______

on Forest from N of Pacific to N of Belvidere

REMARKS:

W.A. Graham Foreman.

FIG. 198.—Foreman of Cable Crew daily report.

of cable from the day it is purchased until it is consigned to the scrap heap.

The information for the first left-hand column is gathered first from the foreman's daily report (Fig. 198). This report

can be used for pulling in or pulling out cable. In the left-hand upper corner are found the work order number, the report number and the date. This report shows that a length of cable was pulled in, its feeder, number being E-1300 giving street and manhole numbers, length pulled in, reel number, if there is any cable left on the reel, and where it went to or where taken from. If there is cable left on the reel, it is recorded as shown, as well as the amount of scrap, manufacturer's name, description of cable, remarks, new or old cable, etc., kind of work, construction, repairs, etc., street location, remarks, foreman's name. On the

WORK ORDER
6502 - 1
6501 - 7
8

KANSAS CITY POWER & LIGHT COMPANY
Cable Splicer's Daily Report
UNDERGROUND DEPARTMENT

Jan 4 1925

KIND OF WORK	LOCATION OF WORK	No. of Cable	Size of Cable	No. of Joints	NAME	HOW EMPLOYED	HOURS
Const.	Forest & Belvidere	E1300	3/0 3C	1	C.F.Crockett	Splicer	8
			13200V		F.J.Akers	Helper	8

REMARKS
Installing Cable racks, forming Cable and making, splice complete in M.H.# 408.

C.F.Crockett
Splicer

FIG. 199.—Cable splicer's daily report.

reverse side of the report there are cross-sections printed. These are used by the foreman to mark out as ducts, giving the location of the cable installed.

The splicing information is gathered from the cable splicer's daily report (Fig. 199). Here we have the work order number, date, kind of work, location, cable number, size of cable, voltage number of splices, names of splicer and helper, and remarks On the reverse side of the report is found the record of the duct, amount of scrap cut off, length of cable in manhole, length of manhole, location, cable number, and manhole number.

The Cable Summary Card.—Figure 200 is used for a record of total length of cable, from the pothead at the power house to the

substation pothead. Each length is added to the preceding length. This record is used for fault location and is the net length of cable after splicing which is determined by checking the cable in manholes after splicing is completed. These measurements are made up in loose-leaf form for the cable testers' use in locating faults.

Blueprint pocket books are furnished the men while installing cable or splicing cable or doing any other work on the underground system. These books give the location of manholes, their number, duct formation, cables in ducts, with cable numbers

Fig 194

KANSAS CITY POWER & LIGHT CO.
SUMMARY CARD

UNDERGROUND DEPARTMENT CABLE NO. P1321

LENGTH NO	DISTANCE FROM P H OR S S	CABLE CARD NO	LENGTH NO	DISTANCE FROM P H OR S S	CABLE CARD NO.
Switch 632	35' 3"	698			
724	220' 9"	699			
400	643'	700			
401	909'	701			

FIG. 200.—Summary card record for total lengths.

and a map giving the route on streets. These hand books are divided into several sections of the city and are divided in relation with the power house or substation in the districts. The center-to-center measurements are also given. Figures 201 and 202 are sample sheets from one of the pocket books.

System of Station and Cable Numbering.—In all electric light, power and railway systems, from the generating stations to the substations, there are a number of transmission feeders, and from the substations to feeding or customer services are a number of circuits, both overhead and underground. In order that the different cables may be known for operating purposes as well as for locating faults, some system of numbering must be established.

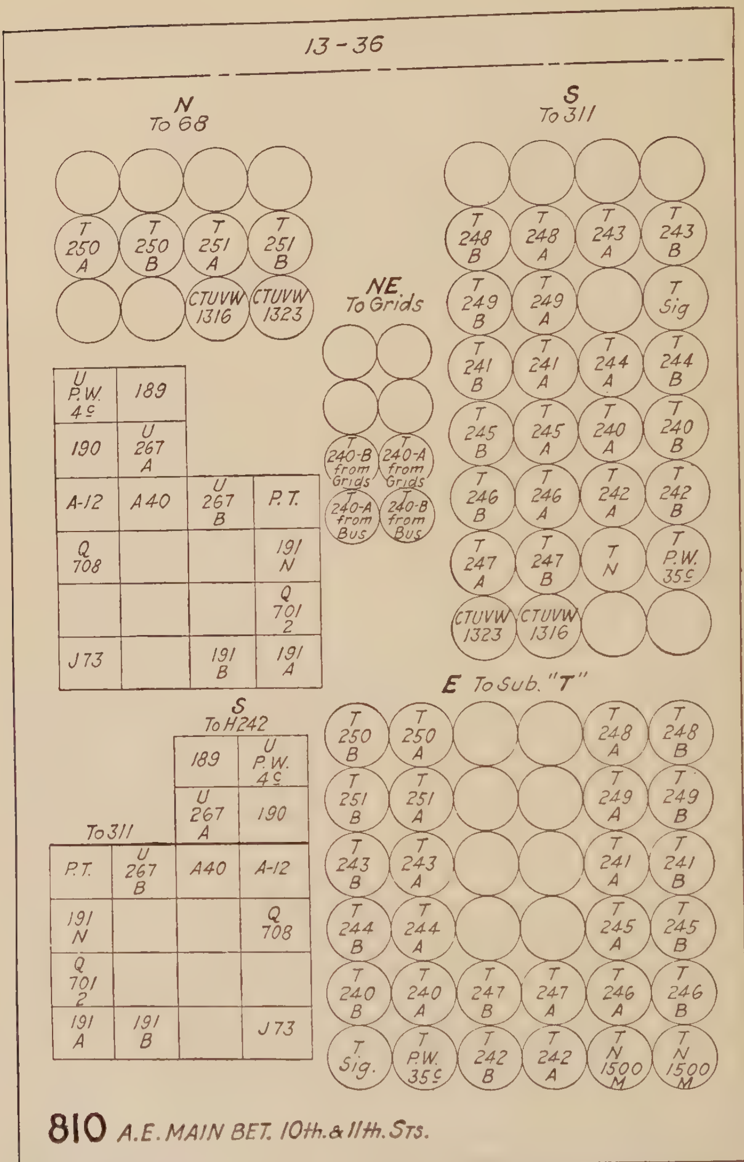


FIG. 201.—Blue print pocket book records showing conduits, cable, location, etc.

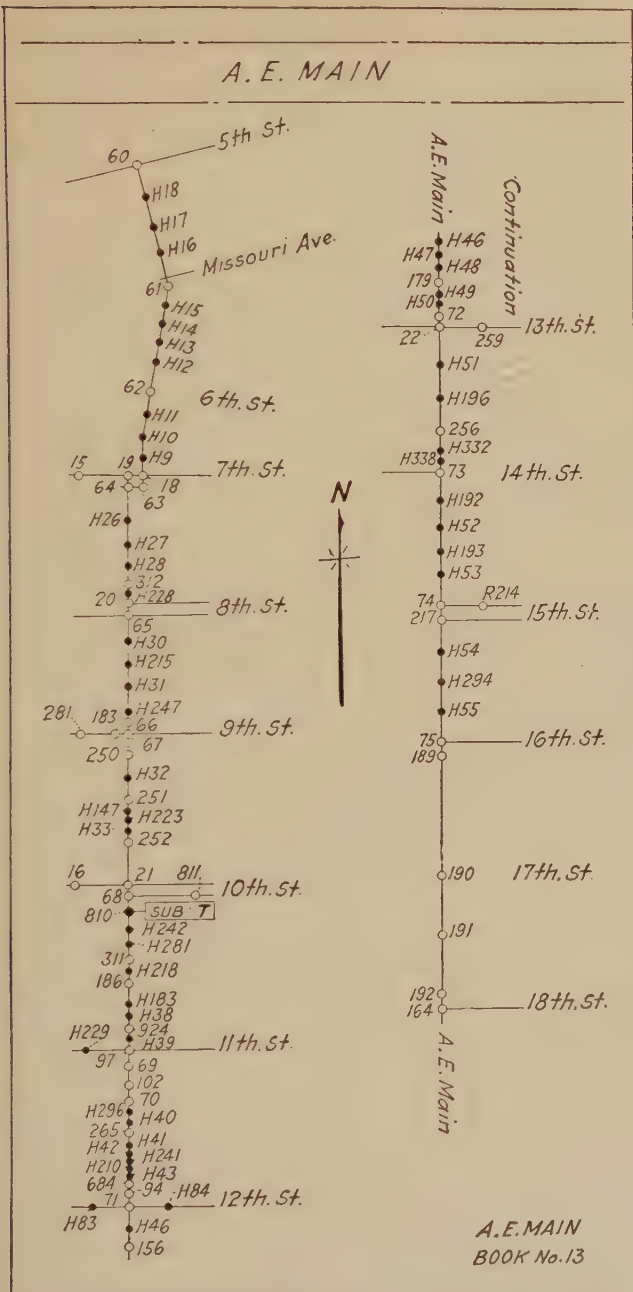


Fig. 202.—Blue print pocket book recorks showing conduits, cable, location, etc.

In connection with a street railway system the numbering is comparatively simple, there being only transmission and distribution cables, that is power feeders, three-phase a.-c. and 600-volt d.-c. positive feeders and negative feeders.

First, the numbering of power stations must be decided, and, in connection with a street railway system, the power stations may be numbered from Nos. 1 to 10 inclusive.

Distribution Stations.—Substations or terminal points each have a number from 11 to 1,000.

Feeder Numbers.—Three-phase a-c. numbers consist of three parts—first, the number of the station from which the feeder goes; second, a letter distinguishing cables between the same stations; third, the numbers of the station to which the cable goes. Example: Cable between power house No. 1 and substation No. 11 are as follows: 1-A-11, 1-B-11, 1-C-11, etc.

The 600-volt positive circuit numbers consist of two parts—first, the number of the station from which the circuit goes; and second, the relative number, 1 to 99 inclusive, of the circuit. Example: Positive circuits from station No. 11 are as follows: 11-1, 11-2, 11-3, etc.

Negative Circuits.—Numbers consist of two parts—first, the number of the station from which the circuit goes; and second, the relative number, 101 to 199 inclusive. The circuits from station No. 11 are 11-101, 11-102, 11-103, etc. This system will readily show from what power station cable is coming and to what station it is going, so that a man working in a manhole can check the feeder or circuit he is to work on. All the cables should be tagged and a blueprint-book record carried for checking the tags.

Numbering power and light cables is more complicated than numbering railway cables, due to the operation of cables for many purposes and at various voltages. The generation may be at 13,200 volts, this may go to an outdoor substation and be stepped up to 33,000 volts or may be stepped down to 4,000 volts, etc. So it is necessary to have not only a schedule for numbering cables but also to have a system of tags that will instantly be recognized one from the other. This is accomplished by making tags in various shapes. The tags should be of generous size and the letters and figures should be raised rather than stamped. Tags with the lettering or numbering stamped into the metal usually fill up with dirt in a short while and are hard to read. Brass

or copper tags should be avoided. They corrode too easily and it is very difficult to read them. The cast-lead tags with the raised lettering and numbering are the best. They will not corrode and are easy to read. This kind of tag is shown in Fig. 203. They are cast in a small hand flask made of steel. Dies are cut out for the various shapes and are set into the flask as desired. The slot which holds the letters and figures is made wedge shaped, the letters or figures being put in from the back. The proper number of blank spaces are put in place and the handle screwed in place which holds the letters in place.

Fig. 203.—Cast lead cable tag with raised figures.

When it is necessary to have two lines of letters and figures on a tag, a plate is used with two slots so that two lines of type can be used. The tags are about 3/16 in. thick and are made of a mixture of five parts lead and one part type metal. The type metal gives them a hard surface and will cause the metal to run into sharp corners.

This system of tagging cable is being used by several power and light companies. Here, there are the same problems as explained for street-railway system but with a larger variation. In this system there are eleven designs of tags. In a power and light system there are a larger number of feeders and circuits as well as several distinct distribution systems, so that it becomes necessary to classify them by a definite design of tag which will be noticeable at a glance in a manhole where there are a large number of cables. If the tags were all of the same design, it would be necessary to look over a large number of tags before the one sought was found. There may be four transmission cables, six distribution cables of one voltage, and six cables of another voltage. If these cables are numbered with a certain series and a definite design, the cables in the manhole are easily classified at a glance. This will eliminate two designs leaving only one design to look over. This in time of emergency will save time and confusion. In this system of numbering, the number of generating stations is not taken into account because there is only one generating station.

Feeder Numbers Consist of Three Parts.—The three parts of which feeder numbers consist are: first, the letter indicating the substation to which the feeder is going; second, the number indicating the voltage of the feeder; third, the number of the feeder. The schedule is planned to use for 13,000-volt feeders, numbers 1301 to 1399. Example: Cable between power house and sub-

station P is as follows: P 1321 and each letter or each number before the feeder number indicates that the feeder goes to each of these substations. Example: Cable between power house and substations T. C. U. V. W. as follows: T. C. U. V. W. 1323. The numerals 1 or 2 indicate cables in parallel. Example: A1309-1; A1309-2. This tag is a 10-point star as shown in Fig. 204.

Feeders from substations may be operated at 13,000 volts, but are numbered 1401 to 1499, so as to classify them. The letter before the number indicates the substation origin. Example: Q1,407. This tag is a 10-point star as shown in Fig. 204.

The 6,600-volt, 25-cycle circuit numbers consist of three parts —first, the letter before the circuit number indicating the substation destination; second, the number 7 representing the

FIG. 204.

FIG. 205.

FIG. 206.

FIG. 204.—Cast lead cable tag used for 13,200 volt feeder.
FIG. 205.—Cast lead cable tag used for 6,600 volt feeder.
FIG. 206.—Cast lead cable tag used for 4,000 volt circuits.

voltage; third, the cable or circuit number. This tag is a four-point star, as Fig. 205.

The 4,000-volt, 60-cycle circuit numbers consist of three parts —first, the letter before the number indicates the substations; second, the first number indicates the voltage; and the next number the circuit number. The schedule is planned to use numbers 376 to 399 for street-lighting multiple circuits; 400 to 499 for four-wire lighting circuits; 500 to 599 for three-wire power circuits. Example: E410. When single-conductor cable is used, the letter after the number indicates the phase. Example: E410-A. This tag is a square (see Fig. 206).

Edison mains are numbered from 1 to 299 and consist of one part on three-conductor mains, and two parts when one-conductor cable is used. First is given the number, and second the letter after the number which indicates polarity. A = positive; B = negative; N = neutral. This tag is a cloverleaf shape as shown in Fig. 207. Example: 280-A.

The Edison circuit numbers consist of three parts—first, the letter before the number indicates the substations; second, the

number indicates the voltage and circuit number; third, the letter after the number indicates polarity. The schedule calls for numbers 201 to 299. Examples: V201-A, W220-B, T240-B. This tag is round as shown in Fig. 208.

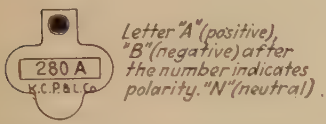


FIG. 207.—Cast lead cable tag used for Edison mains.

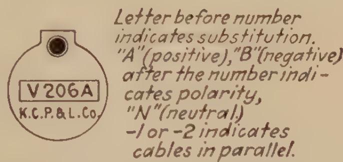


FIG. 208.—Cast lead cable tag used for Edison circuits.

The Edison service circuit numbers consist of two parts—the name or abbreviation denotes the customer; 1 or 2 indicates cables in parallel. A, B, or N indicates polarity. This is an elliptical tag. Example: Newman A. Balt.-1-A, as shown in Fig. 209.

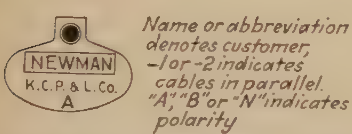


FIG. 209.—Cast lead cable tag used for Edison services.

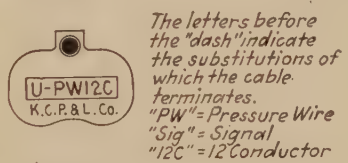


FIG. 210.—Cast lead cable tag used for signal or pressure.

Signal and pressure wire cable numbers consist of three parts. First, the letter before the dash indicates the substations of which the cable terminates; second, the "PW" indicates pressure wire, or "Sig." indicates signal; third, "12c" indicates 12 conductors.

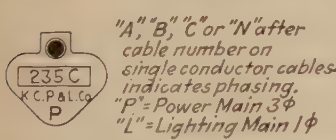


FIG. 211.—Cast lead cable tag used for low voltage A. C.

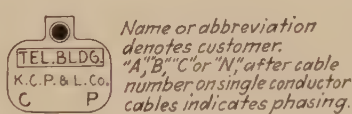


FIG. 212.—Cast lead cable tag used for service low voltage A. C.

This tag is shown in Fig. 210. Example: U-PW12c or R-Sig.12c.

The low-voltage a.-c. main numbers consist of three parts. First, the number; second, the phase; third, "P" indicates power main three-conductor. "L" indicates lighting main one-conductor. Example 235C.P.155B.L. The tag is shown in Fig. 211.

The low-voltage a.-c. service numbers consist of three parts. First, the name or abbreviation denotes customer; second "A," "B," "C," or "N" after cable number on single conductor cables indicates phasing. Example: Tel. Bldg. C.P.; Tel. Bldg. B.L. The tag is shown in Fig. 212.

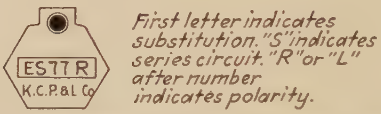


FIG. 213.—Cast lead cable tag used for series street lighting.

The series street-lighting circuit numbers consist of three parts. First, the letter indicates the substation; "S" indicates series circuit; "R" or "L" after the number indicates polarity. Example: ES-77-R or PS-88-L. The tag is shown in Fig. 213.

These tags are fastened to the cables by No. 10 soft-drawn copper wire.

CHAPTER XII

FIREPROOFING UNDERGROUND CABLES

When there are a number of cables in a manhole, conducting power of various voltages and amperages, one cable may fail and cause a fire in the manhole by burning the cable above or below it in the manhole, and, if not noticed in time, may cause a general shutdown of the system. The need of generous separation and tight joints in the conduit construction has been emphasized by the writer for the same reason, and, likewise, it is necessary to protect the cables in the manhole from short-circuits and arcs, and some sort of fire-resisting material should separate them. Brick and concrete shelving have been constructed in manholes for this purpose. Split-tile duct has also been used as shelves for enclosing the cables, and where cables are installed on cable racks, asbestos fireproofing has been used. For this two layers of asbestos felt are dipped in silicate of soda and applied to the cable with joints overlapping. The surface is then covered with a finishing coat of silicate applied by hand, but the hands should be protected by rubber gloves.

Portland cement is used for fireproofing cables and is applied in several ways. In one method hot paraffin is poured over the lead, a layer of untreated cotton tape is applied, and hot paraffin again poured over the tape. This is done to prevent corrosion of the lead by free lime sometimes found in portland cement. However, specifications for the purchase of cement can cover this point. Use lime-free portland cement and the paraffin and tape can be omitted. Expanded-metal wire mesh covered with baked clay and ¼-in. rope is used to support the cement. The rope should be soaked in water and wrapped around the cable with a ¼-in. space between turns. A mixture of three parts of portland cement with four parts of clean, sharp sand of the consistency of putty is applied by hand with rubber gloves. If the rope has been applied so long before that it has become dry, it should be sprinkled with water again. The first coat of cement is applied about ¼ in. thick and allowed to set

for 1 hr. and then another 1/4 in. is applied. A hard, smooth finish is secured by using a short piece of fiber conduit split and used as a finishing trowel.

There is a special cement used for fireproofing called, "asbestoment." This can be used in connection with asbestos felt. The felt can be soaked or immersed in a thin mixture (two parts of special cement to three parts of water) the mixture being stirred until the asbestos felt is well impregnated. A single layer of asbestos felt is applied by wrapping around the cable, butting the edges. The joints between the edges are filled with the mixture. The thickness of felt can be 1/8 or 1/4 in. Two layers of felt can be applied as described or one wrapping of felt coated with special cement to a thickness of 1/16 to 3/8 in., using three parts of special cement to one part of water.

Many tests have been made by engineers to compare the methods of application and materials as well as the fire-resisting qualities of the fireproofing. Portland-cement fireproofing has about the same ability to resist the damaging action of an external arc as asbestos fireproofing with two layers of 3/16-in. material applied with joints overlapped and set with silicate of soda solution, provided the cables are not subject to movement by expansion and contraction so as to cause the breaking up of the cement.

Asbestos fireproofing applied as indicated, using asbestoment as a filler and setting agent has a higher resistance to the abrasive action of an external arc than either of the foregoing and when subjected to bending shows 80 per cent more value than either the cement and rope or asbestos with silicate soda.

Asbestos using special cement as a setting agent costs approximately 50 per cent more than cement fireproofing, therefore the values obtained when considered on a comparative basis, are about in relation to the money expended. Engineers should choose between these two methods according to the character of their plant and the amount of protection or insurance they wish to provide.

Heat Conductivity of Fireproofing.—A comparison has been made of cement fireproofing, asbestos fireproofing, and asbestos with special cement with respect to their heat-conducting properties. The tests were performed by measuring the power input to the heating coil of the test pieces at intervals throughout a period of several hours until a constant temperature difference

between the heated oil and the outside air had been reached. The temperature of the oil was taken as its reading of the upper thermometer; the reading of the lower thermometer varied considerably with its position with respect to the heating coil.

SUMMARY OF TEST RESULTS

Kind of fireproofing	Power input, watts	Temperature rise, degrees centigrade	Rate of heat flow, watts per degree centigrade
Cement	136.0	50.6	2.69
Cement	103.5	38.9	2.79
Cement	85.5	31.2	2.74 Avg. 2.74
Asbestos and silicate	139.4	62.2	2.24
Asbestos and silicate	75.8	35.0	2.16 Avg. 2.20
Asbestos and asbestoment	132.0	61.1	2.16
Asbestos and asbestoment	71.2	33.4	2.13 Avg. 2.14

Based upon the asbestos fireproofing, the results obtained with both asbestos test pieces are nearly the same as would be expected. The cement fireproofing has a relative heat conductivity of 125 per cent. These tests give a true comparison of heat conductivity since the thickness and area of heat insulation were the same for all test pieces.

Cable-sheath Bonding.—Bonding the lead sheaths of all the cables in each manhole is a standard practice and should be done. Tinned-copper wire should be used for the purpose and should be of ample size to prevent melting and burning the lead on the cables. A No. 4 tinned, soft-drawn, 64-strand wire is a good bonding wire for this purpose. Larger cables are used by some power companies in many cases. Scrap cable is used in the manhole for a bus, and No. 4 stranded wire is soldered to the bus. When this method is used, the lead sheath is left on the old cable. The lead sheath is cut at points where tree branches are made. This cut is made through the insulation and when the wires are soldered on they are soldered to the copper and lead at the same time. These joints are wiped by the jointers so that a copper bus protected by lead results. Sewer or other gases and chemical action cannot injure the copper. Tinned copper wire is about the cheapest material for this purpose, however, when the scrap cable is not at hand. When a bonding bus is installed in

the manhole it should be placed convenient to all the cables and a branch wire should be provided for each cable installed as well as future cables. To solder the bond wires to the cable sheath a space about $\frac{3}{4}$ in. wide and 3 in. long should be carefully shaved clean. Care must be taken not to cut too deeply into the lead with the shave hook and not to burn the lead when tinning. This will weaken the sheath and the best-looking job might break off. After shaving the lead rub with stearine wax and put pasters around the space to be tinned. This will make a neat job and will allow the jointers to make a solid bond at the lead sheath. Lay the bond wire lengthwise with the cable fastened temporarily with small iron wire to hold it in place while soldering is being done. After soldering is completed remove the iron wire and pasters. Bonding wires should be long enough not to interfere with the installation of additional cables and should not interfere with the racking of cables around the manhole.

CHAPTER XIII

CABLE CHARACTERISTICS—HEATING LIMITS FOR CABLES[1]

The maximum safe-limiting temperatures in degrees centigrade at the surface of conductors in cables is given in the Standardization Rules of the A. I. E. E. (1918) as follows:

For impregnated-paper insulation (85-E).

For varnished cambric (75-E).

For rubber insulation (60-0.25E).

Where E represents the effective operating e.m.f. in kilovolts between conductors, and the numerals represent temperature in degrees centigrade. Thus, at a working pressure of 5 kv., the maximum safe-limiting temperature at the surface of the conductors in a cable would be:

For impregnated-paper insulation (80°C.).

For varnished-cambric insulation (70°C.).

For rubber-compound insulation (58.75°C.).

The actual maximum safe continuous-current load for any given cable is determined primarily by the temperature of the surrounding medium and the rate of radiation. This current value is greater with direct current than with alternating current and decreases with increasing frequency, being less for 60 cycles than for 25 cycles. The carrying capacity of cables will therefore be less in hot climates than in cooler climates and will be considerably increased during the winter.

Cables immersed in water, carrying at least 50 per cent more than when installed in a four-duct line, and when buried in the earth 15 to 30 per cent more than in a duct line, depending upon the character of soil, moisture, etc. Circulating air or water through conduits containing lead-covered cables will increase their capacity. From the above it is evident that no general rule relative to carrying capacity can be formulated to apply in all cases, and it is necessary, therefore, to consider carefully the surroundings when determining the size of cables to be used.

[1] By W. Nesbit in his book published by Westinghouse Technical Night School, 1926.

The practicability of tables which specify carrying capacity for cables installed in ducts will generally be questioned, for the reason that operating conditions are frequently more severe than those upon which table values are based. A duct line may operate at a safe temperature throughout its entire length, except at one isolated point adjacent to a steam pipe or excessive local temperatures due to some other cause. If larger cables are not employed at this point, burn-outs may occur here when the remainder of the cable line is operating well within the limits of safe operating temperature. The danger in using table values for carrying capacity without carefully considering the condition of earth temperatures throughout the entire duct length is thus evident.

Heating of Cables—Table XXIV.—The basis upon which the data in Table XXIV have been calculated is covered by footnotes below the table. The kva. values are determined from the current in ampers and are based upon 30°C. rise and a maximum of 3,000 volts.[1] Expressing the carrying capacity of cables in terms of kva. (corrected for the varying thickness of insulation required for various voltages) may be found more convenient than the usual manner of expressing it in amperes. It will be noted that the kva. values of the table are on the basis of a four-duct line and that for more than four ducts in the line the table kva. values will be reduced to the following:

For a 4-duct line, 100 per cent.
For a 6-duct line, 88 per cent.
For an 8-duct line, 79 per cent.
For a 10-duct line, 71 per cent.
For a 12-duct line, 63 per cent.
For a 16-duct line, 60 per cent.

When applied to all sizes of cables, the above values are only approximate. The reduction of carrying capacity caused by the presence of many cables is more for large cables than for small ones. Also, where load factors are small, the reduction due to the presence of many cables is less than the value assigned, although the carrying capacity of a small number of cables is only slightly affected.

[1] These current values are taken from General Electric *Bull.* 49302, dated March, 1917. They are in general slightly higher than those published by the Standard Underground Cable Company in their "Hand Book," dated 1906.

TABLE XXIV.—CARRYING CAPACITY OF INSULATED-COPPER CONDUCTORS

The following values for carrying capacity must not be assumed unless it is positively known that the conditions upon which they are based will not be exceeded in service.

Three-conductor cables

B & S No. Area in circular mils	XX Carrying capacity in amperes direct current. Based upon 30°C. rise and a maximum of 3,000 volts. Paper insulation	Kva. which may be transmitted at three phase, and the following voltages over *paper-insulated, lead-covered* cables installed in a *four-duct* line with 30°C. rise in temperature based upon the assumption that all ducts carry **loaded cables and upon a normal earth temperature of 20°C.** For a six-duct line, these kva. values would be reduced to approximately 88 per cent for an eight-duct line, to 79 per cent for a ten-duct line, to 71 per cent for a twelve-duct line, to 63 per cent and for a sixteen-duct line (4 wide and 4 high), to 60 per cent of the table values XXXX.																
		220 volts	440 volts	550 volts	1,100 volts	2,200 volts	3,300 volts	4,000 volts	6,000 volts	6,600 volts	10,000 volts	11,000 volts	12,000 volts	13,200 volts	15,000 volts	20,000 volts	22,000 volts	25,000 volts
14	18	7	14	17	34	68	103	124	184	202	300	328	356	390	438	570	620	693
12	22	8	17	21	42	84	125	152	225	247	367	400	435	477	536	695	757	847
10	30	11	23	28	57	114	171	206	307	336	500	547	595	650	730	950	1,035	1,155
8	40	15	30	38	76	152	228	275	410	450	667	730	792	867	975	1,265	1,380	1,540
6	55	21	42	52	104	209	314	378	562	616	917	1,000	1,090	1,190	1,340	1,740	1,895	2,120
4	70	26	53	66	133	266	400	482	715	785	1,170	1,275	1,385	1,520	1,710	2,215	2,410	2,700
2	95	36	72	90	180	361	543	655	970	1,065	1,585	1,730	1,880	2,060	2,310	3,000	3,270	3,650
1	110	42	84	105	209	418	628	755	1,125	1,230	1,840	2,050	2,180	2,390	2,680	3,480	3,780	4,240
0	130	49	99	123	247	495	740	895	1,330	1,460	2,170	2,370	2,580	2,820	3,170	4,120	4,470	5,000
00	150	57	114	143	285	570	855	1,030	1,535	1,710	2,500	2,740	2,970	3,260	3,660	4,750	5,170	5,770
000	170	65	130	162	323	647	970	1,170	1,740	1,940	2,840	3,100	3,370	3,690	4,150	5,375	5,850	6,550
0000	200	76	152	190	380	760	1,140	1,375	2,040	2,240	3,340	3,650	3,960	4,340	4,870	6,325	6,900	7,700
250.000	225	86	172	214	428	857	1,285	1,550	2,300	2,520	3,750	4,100	4,450	4,880	5,470	7,125	7,750	8,650
300.000	250	95	190	238	475	950	1,430	1,720	2,560	2,800	4,170	4,550	4,950	5,425	6,100	7,900	8,600	9,625
350.000	230	106	213	266	532	1,065	1,600	1,925	2,860	3,140	4,670	5,100	5,550	6,070	6,825	8,850	9,650	10,800
400.000	310	118	236	295	590	1,180	1,770	2,130	3,170	3,480	5,170	5,650	6,150	6,720	7,550	9,800	10,700	11,950
450.000	340	129	258	323	647	1,295	1,940	2,340	3,480	3,810	5,670	6,200	6,750	7,370	8,300	10,750	11,700	13,100
500.000	360	137	274	342	685	1,370	2,050	2,480	3,680	4,040	6,000	6,550	7,130	7,800	8,770	11,400	12,400	13,850
600.000	400	152	304	380	760	1,520	2,280	2,760	4,100	4,500	6,680	7,300	7,920	8,680	9,750	12,650	13,800	15,400
700.000	470	179	358	447	895	1,790	2,680	3,240	4,800	5,270	7,820	8,570	9,300	10,200	11,450	14,850	16,200	18,100

TABLE XXIV.—CARRYING CAPACITY OF INSULATED-COPPER CONDUCTORS.—(*Continued*)

The following values for carrying capacity must not be assumed unless it is positively known that the conditions upon which they are based will not be exceeded in service.

Single-conductor cables

B & S No. Area in circular mils	Carrying capacity in amperes direct current: N. E. code interior conductors: X Table A, rubber insulation	X Table B, other insulation	XXX Based upon 30 C. rise and maximum of 3,000 volts. Paper insulation	Kva. which may be transmitted at three phase and the following voltages over three *paper-insulated, lead-covered* cables installed in a *four-duct* line with 30°C. rise in temperature based upon the assumption that all ducts carry loaded cables and upon a normal earth temperature of 20°C. For a six-duct line, these kva. values would be reduced to approximately 88 per cent for an eight-duct line, to 79 per cent for a ten-duct line to 71 per cent for a twelve-duct line, to 63 per cent and for a sixteen-duct line (4 wide and 4 high), to 60 per cent of the table values XXXX. 220 volts	440 volts	550 volts	1,100 volts	2,200 volts	3,300 volts	4,000 volts	6,000 volts	6,600 volts	10,000 volts	11,000 volts	12,000 volts	13,200 volts	15,000 volts	20,000 volts	22,000 volts	25,000 volts
14	15	20	24	9	18	23	46	92	137	165	245	270	400	437	475	520	585	758	826	925
12	20	25	30	11	23	28	57	114	171	206	306	337	500	547	595	650	732	948	1,033	1,155
10	25	30	40	15	30	38	76	152	228	275	408	450	667	730	792	868	975	1,265	1,378	1,540
8	35	50	55	21	42	52	104	209	314	378	560	617	917	1,010	1,090	1,195	1,340	1,740	1,895	2,120
7																				
6	50	70	75	28	57	71	142	284	428	515	765	842	1,250	1,270	1,485	1,630	1,830	2,370	2,580	2,890
5	55	80																		
4	70	90	95	36	72	90	181	362	540	653	970	1,065	1,585	1,730	1,880	2,060	2,320	3,000	3,270	3,660
3	80	100																		
2	90	125	125	47	95	119	237	475	712	860	1,275	1,405	2,085	2,280	2,480	2,710	3,050	3,950	4,300	4,820
1	100	150	150	57	114	143	285	570	855	1,030	1,530	1,685	2,500	2,715	2,970	3,260	3,660	4,740	5,170	5,780
0	125	200	170	65	130	162	323	647	970	1,170	1,740	1,910	2,830	3,100	3,370	3,690	4,150	5,380	5,850	6,550
00	150	225	200	76	152	190	380	760	1,140	1,380	2,040	2,280	3,330	3,650	3,960	4,350	4,880	6,320	6,880	7,700
000	175	275	230	87	175	219	437	875	1,310	1,580	2,350	2,620	3,840	4,200	4,550	5,000	5,600	7,270	7,920	8,860
0 000	225	325	270	103	205	256	512	1,025	1,540	1,860	2,760	3,030	4,500	4,920	5,350	5,850	6,580	8,530	9,300	10,400

250,000	.....	.....	300	114	228	285	570	1,140	1,710	2,060	3,070	3,370	5,000	5,470	5,950	6,500	7,320	9,500	10,350	11,550
300,000	275	400	340	129	259	324	647	1,295	1,940	2,340	3,470	3,820	5,670	6,200	6,730	7,380	8,300	10,750	11,700	13,200
350,000	.....	.....	380	144	289	362	723	1,445	2,170	2,620	3,880	4,270	6,330	6,920	7,520	8,250	9,260	12,000	13,100	14,650
400,000	325	500	410	156	312	390	780	1,560	2,340	2,820	4,180	4,600	6,850	7,480	8,120	8,900	10,000	12,950	14,150	15,800
450,000	.....	.....	450	172	343	428	855	1,710	2,560	3,100	4,600	5,050	7,500	8,200	8,900	9,770	10,900	14,200	15,500	17,350
500,000	400	600	480	183	365	456	912	1,825	2,740	3,300	4,900	5,400	8,000	8,750	9,500	10,400	11,700	15,200	16,550	18,500
600,000	450	680	550	209	418	522	1,045	2,090	3,140	3,790	5,620	6,180	9,170	10,000	10,900	11,950	13,400	17,400	18,950	21,200
700,000	500	760	610	232	464	580	1,160	2,320	3,480	4,200	6,220	6,850	1,0150	11,100	12,100	13,250	14,850	19,300	21,000	23,500
800,000	550	840	670	255	510	638	1,275	2,550	3,820	4,600	6,850	7,520	11,150	12,200	13,250	14,550	16,350	21,200	23,100	25,800
900,000	600	920	720	274	548	685	1,370	2,740	4,100	4,950	7,350	8,100	12,000	13,150	14,250	15,650	17,550	22,700	24,800	27,700
1,000,000	650	1,000	780	297	594	742	1,480	2,960	4,450	5,370	7,950	8,750	13,000	14,200	15,450	16,950	19,000	24,650	26,800	30,100
1,100,000	690	1,080																		
1,200,000	730	1,150																		
1,250,000	....	.....	900	342	685	855	1,710	3,420	5,130	6,200	9,200	10,100	15,000	16,400	17,800	19,550	21,900	28,400	31,000	34,700
1,300,000	770	1,220																		
1,400,000	810	1,290																		
1,500,000	850	1,360	1,030	392	785	980	1,960	3,920	5,870	7,100	10,500	11,550	17,200	18,800	20,400	22,400	25,100	32,600	35,500	39,700
1,600,000	890	1,430																		
1,750,000	....	.....	1,130	430	860	1,075	2,150	4,300	6,450	7,770	11,550	12,700	18,800	20,600	22,400	24,500	27,500	35,700	39,000	43,600
1,900,000	1,010	1,610																		
2,000,000	1,050	1,670	1,260	480	960	1,200	2,400	4,800	7,200	8,670	12,850	14,150	21,000	23,000	25,000	27,300	30,700	39,800	43,300	48,600

TABLE XXV.—INDUCTANCE, REACTANCE, AND IMPEDANCE, AT 25 CYCLES, PER MILE OF SINGLE CONDUCTOR FOR THREE-CONDUCTOR CABLES

Area in circular mils B & S No.	Diameter in inches	Resistance per mile in ohms*	Insulation thickness in 64ths of an inch†											
			3/64 by 3/64			4/64 by 4/64			5/64 by 5/64			6/64 by 6/64		
			Inductance, milli-henries	Reactance, ohms	Impedance, ohms	Inductance, milli-henries	Reactance, ohms	Impedance, ohms	Inductance, milli-henries	Reactance, ohms	Impedance, ohms	Inductance, milli-henries	Reactance, ohms	Impedance, ohms
500,000	0.814	0.116	0.338	0.0530	0.128	0.349	0.0547	0.129	0.360	0.0565	0.129	0.370	0.0580	0.130
450,000	0.772	0.129	0.340	0.0534	0.140	0.351	0.0552	0.140	0.362	0.0568	0.141	0.373	0.0585	0.142
400,000	0.728	0.145	0.343	0.0537	0.155	0.354	0.0554	0.155	0.367	0.0576	0.155	0.377	0.0592	0.157
350,000	0.681	0.166	0.346	0.0542	0.175	0.357	0.0560	0.176	0.370	0.0581	0.176	0.380	0.0596	0.177
300,000	0.630	0.194	0.349	0.0547	0.204	0.361	0.0567	0.204	0.374	0.0587	0.205	0.386	0.0605	0.207
250,000	0.575	0.233	0.353	0.0554	0.240	0.366	0.0575	0.240	0.381	0.0597	0.240	0.394	0.0619	0.242
0,000	0.528	0.275	0.357	0.0560	0.281	0.372	0.0585	0.281	0.387	0.0607	0.282	0.403	0.0633	0.282
000	0.470	0.346	0.362	0.0567	0.352	0.379	0.0595	0.352	0.397	0.0623	0.352	0.411	0.0645	0.353
00	0.418	0.437	0.369	0.0579	0.441	0.388	0.0609	0.442	0.406	0.0637	0.442	0.423	0.0665	0.442
0	0.373	0.550	0.377	0.0592	0.552	0.398	0.0625	0.554	0.417	0.0653	0.554	0.432	0.0677	0.554
1	0.332	0.695	0.384	0.0603	0.697	0.405	0.0635	0.698	0.429	0.0673	0.698	0.447	0.0700	0.699
2	0.292	0.879	0.393	0.0617	0.882	0.417	0.0655	0.882	0.441	0.0691	0.882	0.463	0.0727	0.882
3	0.260	1.11	0.403	0.0633	1.11	0.431	0.0675	1.11	0.454	0.0712	1.11	0.476	0.0746	1.11
4	0.232	1.40	0.413	0.0648	1.40	0.442	0.0695	1.40	0.469	0.0736	1.49	0.494	0.0775	1.40
6	0.184	2.21	0.437	0.0685	2.21	0.470	0.0737	2.21	0.501	0.0785	2.21	0.529	0.0830	2.21

Area in circular mils B & S No.	Diameter in inches	Resistance per mile in ohms*	7/64 by 7/64			8/64 by 8/64			9/64 by 9/64			10/64 by 10/64		
			Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms
500,000	0.814	0.116	0.379	0.0595	0.130	0.389	0.0610	0.131	0.398	0.0625	0.132	0.407	0.0640	0.133
450,000	0.772	0.129	0.384	0.0602	0.143	0.393	0.0617	0.143	0.403	0.0634	0.144	0.411	0.0645	0.145
400,000	0.728	0.145	0.389	0.0610	0.158	0.396	0.0622	0.158	0.409	0.0642	0.159	0.417	0.0655	0.160
350.000	0.681	0.166	0.395	0.0620	0.177	0.402	0.0630	0.178	0.415	0.0652	0.178	0.423	0.0664	0.179
300.000	0.630	0.194	0.399	0.0626	0.207	0.409	0.0642	0.205	0.421	0.0660	0.205	0.431	0.0675	0.206
250.000	0.575	0.233	0.409	0.0642	0.242	0.419	0.0658	0.242	0.430	0.0675	0.242	0.442	0.0693	0.243
0,000	0.528	0.275	0.415	0.0652	0.283	0.427	0.0673	0.283	0.441	0.0690	0.284	0.452	0.0708	0.285
000	0.470	0.346	0.429	0.0673	0.353	0.440	0.0690	0.353	0.455	0.0714	0.354	0.466	0.0730	0.355
00	0.418	0.437	0.439	0.0690	0.443	0.455	0.0714	0.443	0.469	0.0735	0.443	0.483	0.0758	0.444
0	0.373	0.550	0.453	0.0712	0.554	0.466	0.0731	0.554	0.485	0.0760	0.555	0.498	0.0780	0.556
1	0.332	0.695	0.466	0.0732	0.698	0.483	0.0757	0.697	0.501	0.0785	0.699	0.516	0.0810	0.700
2	0.292	0.879	0.483	0.0758	0.882	0.502	0.0787	0.882	0.521	0.0816	0.833	0.537	0.0843	0.883
3	0.260	1.11	0.499	0.0782	1.11	0.519	0.0814	1.11	0.538	0.0845	1.11	0.558	0.0875	1.11
4	0.232	1.40	0.518	0.0813	1.40	0.538	0.0845	1.40	0.558	0.0875	1.40	0.577	0.0905	1.40
6	0.184	2.21	0.557	0.0873	2.21	0.580	0.0910	2.21	0.601	0.0943	2.21	0.622	0.0975	2.21

TABLE XXV.—INDUCTANCE, REACTANCE, AND IMPEDANCE, AT 25 CYCLES, PER MILE OF SINGLE CONDUCTOR FOR THREE-CONDUCTOR CABLES.—(*Continued*)

Area in circular mils B & S No.	Diameter in inches	Resistance per mile in ohms*	Insulation thickness in 64ths of an inch†											
			11/64 by 11/64			12/64 by 12/64			13/64 by 13/64			14/64 by 14/64		
			Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms
500,000	0.814	0.116	0.417	0.0655	0.133	0.427	0.0670	0.133	0.434	0.0681	0.134	0.441	0.0691	0.135
450,000	0.772	0.129	0.423	0.0665	0.145	0.431	0.0675	0.145	0.439	0.0690	0.146	0.449	0.0705	0.147
400,000	0.728	0.145	0.429	0.0673	0.160	0.436	0.0683	0.160	C.446	0.0700	0.161	0.457	0.0717	0.162
350,000	0.681	0.166	0.436	0.0685	0.180	0.446	0.0700	0.180	0.453	0.0710	0.180	0.464	0.0729	0.181
300,000	0.630	0.194	0.444	0.0697	0.206	0.456	0.0715	0.206	0.461	0.0722	0.207	0.473	0.0742	0.208
250,000	0.575	0.233	0.451	0.0712	0.244	0.465	0.0730	0.244	0.475	0.0745	0.245	0.486	0.0762	0.245
0,000	0.528	0.275	0.465	0.0730	0.285	0.476	0.0745	0.285	0.486	0.0760	0.286	0.498	0.0782	0.287
000	0.470	0.346	0.481	0.0755	0.355	0.493	0.0775	0.355	0.503	0.0790	0.355	0.516	0.0810	0.356
00	0.418	0.437	0.498	0.0780	0.445	0.510	0.0800	0.445	0.521	0.0816	0.445	0.535	0.0840	0.446
0	0.373	0.550	0.514	0.0805	0.556	0.528	0.0828	0.556	0.539	0.0845	0.556	0.551	0.0870	0.557
1	0.332	0.695	0.531	0.0830	0.700	0.546	0.0855	0.700	0.559	0.0877	0.700	0.573	0.0900	0.700
2	0.292	0.879	0.551	0.0870	0.882	0.570	0.0895	0.882	0.583	0.0915	0.883	0.598	0.0938	0.884
3	0.260	1.11	0.571	0.0900	1.11	0.591	0.0927	1.11	0.606	0.0950	1.11	0.618	0.0970	1.11
4	0.332	1.40	0.596	0.0935	1.40	0.613	0.0962	1.40	0.627	0.0983	1.40	0.643	0.1010	1.41
6	0.184	2.21	0.643	0.1010	2.21	0.661	0.1037	2.21	0.678	0.1063	2.21	0.696	0.1090	2.21

Area in circular mils B & S No.	Diameter in inches	Resistance per mile in ohms*	16/64 by 16/64			18/64 by 18/64			20/64 by 20/64			22/64 by 22/64		
			Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms
500,000	0.814	0.116	0.457	0.0717	0.136	0.474	0.0744	0.138	0.487	0.0764	0.140	0.501	0.0785	0.141
450,000	0.772	0.129	0.462	0.0725	0.148	0.481	0.0754	0.150	0.496	0.0778	0.151	0.509	0.0800	0.152
400,000	0.728	0.145	0.471	0.0738	0.163	0.487	0.0764	0.164	0.505	0.0792	0.165	0.519	0.0815	0.166
350,000	0.681	0.166	0.480	0.0753	0.182	0.496	0.0778	0.183	0.513	0.0805	0.185	0.529	0.0830	0.186
300,000	0.630	0.194	0.491	0.0770	0.208	0.511	0.0802	0.210	0.526	0.0825	0.211	0.541	0.0848	0.212
250,000	0.575	0.233	0.505	0.0792	0.246	0.524	0.0822	0.247	0.541	0.0848	0.248	0.557	0.875	0.249
0,000	0.528	0.275	0.517	0.0810	0.287	0.536	0.0840	0.288	0.556	0.0870	0.289	0.573	0.0900	0.290
000	0.470	0.346	0.536	0.0840	0.357	0.556	0.0870	0.357	0.575	0.0905	0.358	0.592	0.0930	0.360
00	0.418	0.437	0.552	0.0865	0.446	0.578	0.0907	0.446	0.599	0.0940	0.447	0.618	0.0970	0.448
0	0.373	0.550	0.575	0.0902	0.558	0.601	0.0942	0.558	0.621	0.0972	0.558	0.642	0.1005	0.559
1	0.332	0.695	0.598	0.0938	0.700	0.623	0.0980	0.700	0.645	0.1010	0.701	0.666	0.1045	0.702
2	0.292	0.879	0.623	0.0978	0.884	0.649	0.1017	0.884	0.674	0.1060	0.885	0.693	0.1085	0.886
3	0.260	1.11	0.649	0.1018	1.11	0.674	0.1060	1.11	0.698	0.1095	1.11	0.721	0.1130	1.12
4	0.232	1.40	0.673	0.1055	1.41	0.701	0.1100	1.41	0.725	0.1138	1.41	0.746	0.1170	1.41
6	0.184	2.21	0.725	0.1135	2.22	0.754	0.1180	2.22	0.780	0.1225	2.22	0.809	0.1270	2.22

* Resistance based upon 100 per cent conductivity at 25°C. (77°F.), including 2 per cent allowance for spiral of strands and 2 per cent allowance for spiral of conductors. For a temperature of 65°C. (149°F.) these resistance values would be increased 15 per cent.

† The inductance is in millihenries; the reactance and the impedance are in ohms.

The table values were derived from the equation $L = 0.08047 + 0.741 \log \frac{D}{R}$, where R is the radius of conductor, D the distance between centers of conductors expressed in the same terms as R, and L the inductance in millihenries per mile of each conductor. All values in the table are single phase and based upon a single conductor 1 mile long.

TABLE XXVI.—INDUCTANCE, REACTANCE, AND IMPEDANCE, AT 60 CYCLES, PER MILE OF SINGLE CONDUCTOR FOR THREE-CONDUCTOR CABLES

Area in circular mils B & S No.	Diameter in inches	Resistance per mile in ohms*	Insulation thickness in 64ths of an inch†											
			3/64 by 3/64			4/64 by 4/64			5/64 by 5/64			6/64 by 6/64		
			Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms
500,000	0.814	0.116	0.338	0.127	0.172	0.349	0.131	0.175	0.360	0.136	0.178	0.370	0.140	0.182
450,000	0.772	0.129	0.340	0.128	0.181	0.351	0.132	0.184	0.362	0.137	0.189	0.373	0.141	0.191
400,000	0.728	0.145	0.343	0.129	0.195	0.354	0.134	0.197	0.367	0.138	0.201	0.377	0.142	0.204
350,000	0.681	0.166	0.346	0.130	0.211	0.357	0.135	0.214	0.370	0.140	0.217	0.380	0.143	0.220
300,000	0.630	0.194	0.349	0.132	0.235	0.361	0.136	0.237	0.374	0.141	0.240	0.386	0.145	0.244
250,000	0.575	0.233	0.353	0.133	0.268	0.366	0.138	0.271	0.381	0.144	0.274	0.394	0.149	0.277
0,000	0.528	0.275	0.357	0.135	0.308	0.372	0.140	0.309	0.387	0.146	0.313	0.403	0.152	0.316
000	0.470	0.346	0.362	0.136	0.373	0.379	0.143	0.375	0.397	0.150	0.378	0.411	0.155	0.381
00	0.418	0.437	0.369	0.139	0.460	0.388	0.146	0.461	0.406	0.153	0.464	0.423	0.160	0.466
0	0.373	0.550	0.377	0.142	0.569	0.398	0.150	0.571	0.417	0.157	0.572	0.432	0.163	0.573
1	0.332	0.695	0.384	0.145	0.711	0.405	0.152	0.713	0.429	0.162	0.715	0.447	0.168	0.716
2	0.292	0.879	0.393	0.148	0.893	0.417	0.157	0.894	0.441	0.166	0.896	0.463	0.174	0.896
3	0.260	1.11	0.403	0.152	1.12	0.431	0.162	1.12	0.454	0.171	1.12	0.476	0.180	1.12
4	0.232	1.40	0.413	0.156	1.41	0.442	0.167	1.41	0.469	0.177	1.41	0.494	0.186	1.41
6	0.184	2.21	0.437	0.165	2.22	0.470	0.177	2.22	0.501	0.189	2.22	0.529	0.200	2.22

Area in circular mils B & S No.	Diameter in inches	Resistance per mile in ohms*	7/64 by 7/64			8/64 by 8/64			9/64 by 9/64			10/64 by 10/64		
			Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms
500,000	0.814	0.116	0.379	0.143	0.184	0.389	0.146	0.186	0.398	0.150	0.190	0.403	0.153	0.192
450,000	0.772	0.129	0.384	0.145	0.194	0.393	0.148	0.195	0.403	0.152	0.200	0.411	0.155	0.202
400,000	0.728	0.145	0.389	0.147	0.206	0.396	0.149	0.208	0.409	0.154	0.212	0.417	0.157	0.230
350,000	0.681	0.166	0.395	0.149	0.222	0.402	0.151	0.224	0.415	0.157	0.229	0.423	0.160	0.231
300,000	0.630	0.194	0.399	0.150	0.245	0.409	0.154	0.246	0.421	0.158	0.251	0.431	0.162	0.254
250,000	0.575	0.233	0.409	0.154	0.279	0.419	0.158	0.282	0.430	0.162	0.285	0.442	0.166	0.286
0,000	0.528	0.275	0.415	0.157	0.318	0.427	0.161	0.320	0.441	0.166	0.323	0.452	0.170	0.323
000	0.470	0.346	0.429	0.162	0.383	0.440	0.166	0.385	0.455	0.172	0.388	0.466	0.176	0.389
00	0.418	0.437	0.439	0.166	0.467	0.455	0.171	0.471	0.469	0.177	0.473	0.483	0.182	0.474
0	0.373	0.550	0.453	0.171	0.578	0.466	0.176	0.578	0.485	0.183	0.580	0.498	0.188	0.582
1	0.332	0.695	0.466	0.176	0.718	0.483	0.182	0.697	0.501	0.189	0.720	0.516	0.195	0.721
2	0.292	0.879	0.483	0.182	0.900	0.502	0.189	0.900	0.521	0.196	0.902	0.537	0.202	0.902
3	0.260	1.11	0.499	0.188	1.13	0.519	0.195	1.13	0.538	0.203	1.13	0.558	0.211	1.13
4	0.232	1.40	0.518	0.195	1.41	0.538	0.203	1.41	0.558	0.210	1.42	0.577	0.218	1.42
6	0.184	2.21	0.557	0.210	2.22	0.580	0.219	2.22	0.601	0.226	2.22	0.622	0.234	2.22

* Resistance based upon 100 per cent conductivity at 25°C. (77°F.) including 2 per cent allowance for spiral of strands and 2 per cent allowance for spiral of conductors. For a temperature of 65°C. (149°F.) these resistance values would be increased 15 per cent.

† The inductance is in millihenries; the reactance and the impedance are in ohms.

TABLE XXVI.—INDUCTANCE, REACTANCE, AND IMPEDANCE AT 60 CYCLES PER MILE OF SINGLE-CONDUCTOR FOR THREE-CONDUCTOR CABLES.—(*Continued*)

Area in circular mils B & S No.	Diameter in inches	Resistance per mile in ohms*	Insulation thickness in 64ths of an inch†											
			11/64 by 11/64			12/64 by 12/64			13/64 by 13/64			14/64 by 14/64		
			Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms
500,000	0.814	0.116	0.417	0.157	0.195	0.427	0.161	0.198	0.434	0.164	0.202	0.441	0.166	0.202
450,000	0.772	0.129	0.423	0.160	0.204	0.431	0.162	0.208	0.439	0.165	0.211	0.449	0.170	0.211
400,000	0.728	0.145	0.429	0.161	0.216	0.436	0.164	0.220	0.446	0.168	0.222	0.457	0.172	0.324
350,000	0.681	0.166	0.436	0.164	0.235	0.446	0.168	0.237	0.453	0.171	0.240	0.464	0.175	0.240
300,000	0.630	0.194	0.444	0.167	0.256	0.456	0.172	0.260	0.461	0.174	0.262	0.473	0.178	0.264
250,000	0.575	0.233	0.451	0.171	0.289	0.465	0.175	0.292	0.475	0.179	0.295	0.486	0.183	0.296
0,000	0.528	0.275	0.465	0.175	0.328	0.476	0.180	0.330	0.486	0.183	0.332	0.498	0.188	0.334
000	0.470	0.346	0.481	0.181	0.392	0.493	0.186	0.395	0.503	0.190	0.396	0.516	0.194	0.378
00	0.418	0.437	0.498	0.188	0.476	0.510	0.192	0.479	0.521	0.196	0.480	0.535	0.202	0.492
0	0.373	0.550	0.514	0.194	0.584	0.528	0.199	0.586	0.539	0.203	0.589	0.554	0.209	0.590
1	0.332	0.695	0.531	0.200	0.724	0.546	0.206	0.725	0.559	0.211	0.726	0.573	0.216	0.728
2	0.292	0.879	0.554	0.209	0.905	0.570	0.215	0.906	0.583	0.220	0.908	0.598	0.225	0.910
3	0.260	1.11	0.574	0.216	1.13	0.591	0.222	1.13	0.606	0.228	1.13	0.618	0.233	1.14
4	0.232	1.40	0.596	0.224	1.42	0.613	0.231	1.42	0.627	0.236	1.42	0.643	0.242	1.42
6	0.184	2.21	0.643	0.242	2.22	0.661	0.249	2.22	0.678	0.256	2.22	0.696	0.262	2.23

Area in circular mils B & S No.	Diameter in inches	Resistance per mile in ohms*	$^{16}/_{64}$ by $^{16}/_{64}$			$^{18}/_{64}$ by $^{18}/_{64}$			$^{20}/_{64}$ by $^{20}/_{64}$			$^{22}/_{64}$ by $^{22}/_{64}$		
			Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms	Inductance, millihenries	Reactance, ohms	Impedance, ohms
500,000	0.814	0.116	0.457	0.172	0.208	0.474	0.179	0.212	0.487	0.183	0.217	0.501	0.189	0.222
450,000	0.772	0.129	0.462	0.174	0.218	0.481	0.181	0.224	0.496	0.187	0.228	0.509	0.192	0.232
400,000	0.728	0.145	0.471	0.178	0.230	0.487	0.183	0.235	0.505	0.190	0.240	0.519	0.196	0.244
350,000	0.681	0.166	0.480	0.181	0.246	0.496	0.187	0.252	0.513	0.193	0.254	0.529	0.200	0.260
300,000	0.630	0.194	0.491	0.185	0.270	0.511	0.192	0.274	0.526	0.198	0.279	0.541	0.204	0.282
250,000	0.575	0.233	0.505	0.190	0.302	0.524	0.197	0.306	0.541	0.204	0.311	0.557	0.210	0.314
0,000	0.528	0.275	0.517	0.195	0.338	0.536	0.202	0.342	0.556	0.210	0.348	0.573	0.216	0.352
000	0.470	0.346	0.536	0.202	0.403	0.556	0.209	0.406	0.575	0.217	0.410	0.592	0.223	0.415
00	0.418	0.437	0.552	0.208	0.486	0.578	0.218	0.490	0.599	0.226	0.494	0.618	0.233	0.496
0	0.373	0.550	0.575	0.217	0.592	0.601	0.226	0.596	0.621	0.234	0.599	0.641	0.242	0.602
1	0.332	0.695	0.598	0.225	0.732	0.623	0.235	0.734	0.645	0.243	0.737	0.666	0.251	0.740
2	0.292	0.879	0.623	0.235	0.912	0.649	0.245	0.914	0.674	0.254	0.917	0.693	0.261	0.920
3	0.260	1.11	0.649	0.245	1.14	0.674	0.254	1.14	0.698	0.262	1.14	0.721	0.272	1.14
4	0.232	1.40	0.673	0.254	1.42	0.701	0.264	1.43	0.725	0.273	1.43	0.746	0.281	1.43
6	0.184	2.21	0.725	0.273	2.22	0.754	0.284	2.23	0.780	0.294	2.23	0.809	0.305	2.23

* Resistance based upon 100 per cent conductivity at 25°C. (77°F.) including 2 per cent allowance for spiral of strands and 2 per cent allowance for spiral of conductors. For a temperature of 65°C. (149°F.) these resistance values would be increased 15 per cent.

† The inductance is in millihenries; the reactance and the impedance are in ohms.

Reactance of Three-conductor Cables.—Tables XXV and XXVI contain values for the inductance, reactance, and impedance of round three-conductor cables of various sizes and for the thickness of insulation indicated. All values in the tables are on the basis of one conductor of the cable 1 mile long. The table values were calculated from the fundamental Eq. (4),

$$L = 0.08047 + 0.741 \log_{10} \frac{D}{R} \tag{4}$$

where L = the inductance in millihenries per mile of each conductor, R the actual radius of the conductor, and D the distance between conductor centers expressed in the same units as R. As indicated in Sec. 1, under "Inductance," this formula has been derived on the basis of solid conductors. In the case of cables,

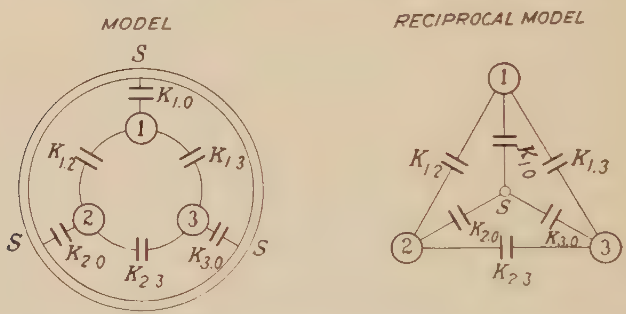


FIG. A.—Representation of capacitances of a symmetrical three-phase cable.

the effective radius is actually slightly less than that of the stranded conductor. The values for inductance, as determined by the fundamental formula, would thus tend to give values several per cent less than the actual when applied to three-conductor cable calculations. On the other hand, spiraling the conductors of three-conductor cables tends to increase their reactance by several per cent. It may, therefore, be assumed that the use of the fundamental formula in the case of three-conductor cables gives results approximately correct. Skin effect on larger cables will, however, tend to decrease the reactance slightly, particularly at 60 cycles.

Capacitance of three-conductor Cables.—Formulas for determining the approximate capacitance of three-conductor cables are cumbersome. They give reasonably accurate results only in the case of a homogeneous dielectric and in cases where the

conductors are small compared to the radius of the sheath. They give inaccurate results in cases of large conductors closely spaced. Figure *A* illustrates the various capacitances of a three-conductor cable. Formulas taken from Russell's "Alternating Currents" have been combined and converted to common logarithms and are given below. They were derived by the method of images and on the assumption that the conductors are round and symmetrically spaced with respect to the axis of the sheath.

$$C_1 = \frac{1}{13.82 \log_{10} \dfrac{R^6 - d^6}{3R^3d^2r}} + \frac{1}{6.91 \log_{10} \left(\dfrac{1.73d}{r} \times \dfrac{R^2 - d^2}{R^4 + R^2d^2 + d^4} \right)} \times 0.179 \times k. \quad (70)$$

$$C_{12} = \frac{}{13.82 \log_{10} \dfrac{R^6 - d^6}{3R^3d^2r}} - \frac{1}{13.82 \log_{10} \left(\dfrac{1.73d}{r} \dfrac{R^2 - d^2}{(R^4 + R^2d^2 + d^4)^{1/2}} \right)} \times 0.179 \times k. \quad (71)$$

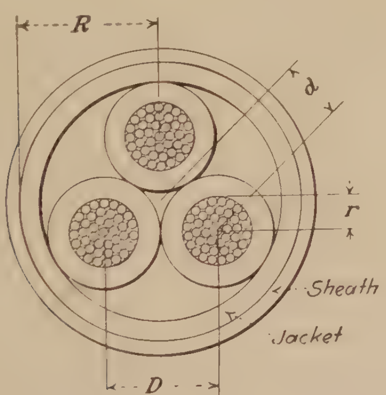


FIG. *B*.—Dimensions of a symmetrical three-phase cable.

R = inside radius of sheath in centimeters (see Fig. *B*).
r = radius of conductor in centimeters.
d = distance between axis of conductor and axis of sheath in centimeters.

K = the dielectric constant. For impregnated-paper insulation, it varies between three and four; for varnished-cambric insulation it varies between four and six; for rubber insulation it varies between four and nine.

$C1$ = capacitance in microfarads per mile between one conductor and the other two conductors plus the sheath.

$C1-2$ = mutual capacitance in microfarads per mile between any two conductors. The capacitance to neutral is twice this value.

$C12$ is used in determining the capacitance for various combinations or arrangements as explained below.

Capacitance and Susceptance. Table XXVII.—Table XXVII contains values for capacitance and susceptance of three-conductor, paper-insulated cable for various sizes of conductors and thicknesses of insulation indicated. All values are based upon a value for K of 3.5 and, as indicated, a thickness of insulation for the jacket the same as that surrounding each conductor. The values were calculated by Eqs. (70) and (71).

The susceptance values given for 25 and 60 cycles are to neutral. In calculating the voltage regulation of circuits, it is general practice to calculate the regulation on the basis of one conductor to neutral. The susceptance between two of the conductors would be half the table values to neutral. The values for susceptance were calculated from the equation,

Susceptance to neutral in micromhos = $2\pi fC$.

Thus, No. 0 three-conductor cable with $\frac{7}{64}$- and $\frac{7}{64}$-in. insulation has a capacitance between conductors of 0.195 microfarads (0.39 microfarads to neutral). The susceptance to neutral at 60 cycles, therefore, is $2\pi 60 \times 0.39 = 147$ microfarads, as indicated by the table.

Inter-relation of Capacitance of Three-conductor Cables.—The following equations for determining the effective capacitance for various arrangements of the three conductors and the sheath are given in Russell's "Alternating Currents."

$$\text{Capacitance between 1 and 2} = \tfrac{1}{2}(C1 - C12) \tag{72}$$

$$\text{Capacitance between 1 and 2, 3} = \tfrac{2}{3}(C1 - C12) \tag{73}$$

Capacitance between 1 and S(2 and 3 insulated) =

$$\frac{(C1 - C12)(C1 + 2C12)}{C1 + C12} \tag{74}$$

Capacitance between 1 and S, 2(3 insulated) =

$$\frac{(C1 - C12)(C1 + C12)}{C1} \qquad (75)$$

Capacitance between 1 and S, 2, 3 = $C1$ (76)

Capacitance between S and 1, 2 (3 insulated =

$2(C1 - C12)(C1 + C12)$ (77)

Capacitance between 1, S and 2, 3 = $2(C1 + C12)$ (78)

Capacitance between S and 1, 2, 3 = $3(C1 + 2C12)$ (79)

$C1$ (76) may be measured in the ordinary way, by reading the throw of a mirror galvanometer and comparing with the throw given by a standard condenser. A further measurement of Eq. (78) or Eq. (79) will give a simple equation to find $C12$. For instance, if measurements were taken of Eqs. (78) and (79) and were found to be:

$2C1 + 2C12 = 0.410$ mf. per mile (78)

And $3C1 + 6C12 = 0.450$ mf. per mile (79)

Therefore $C1 = 0.26$ mf. per mile

$C12 = -0.055$ mf. per mile

Numeral Examples.—From Table XXVII for a 250,000-cir.-mil, three-conductor cable having a band of insulation surrounding each conductor of $^{16}\!/_{64}$ in. and an insulation jacket surrounding all three conductors of the same thickness, the following values are obtained:

$C1 = 0.260$ mf. per mile.

$C12 = -0.055$ mf. per mile.

Then, in the order in which the capacitance increases,

Capacitance between 1 and 2 = 0.157 mf. per mile (72)

Capacitance between 1 and 2, 3 = 0.210 mf. per mile (73)

Capacitance between 1 and S(2 and 3 insulated) = 0.230 mf. per mile (74)

Capacitance between 1 and S, 2 (3 insulated) = 0.248 mf. per mile (75)

Capacitance between 1 and S, 2, 3, = 0.260 mf. per mile (76)

Capacitance between S and 1, 2 (3 insulated) = 0.363 mf. per mile. (77)

Capacitance between 1, S and 2, 3 = 0.410 mf. per mile. (78)

Capacitance between S and 1, 2, 3 = 0.450 mf. per mile. (79)

Comparison of Calculated Capacitance with Test Results.—The difference between measured results of capacitance and the

TABLE XXVII.—CAPACITANCE AND SUSCEPTANCE PER MILE OF THREE-CONDUCTOR, PAPER-INSULATED CABLES

Area in circular mils B & S No.	Insulation thickness in 64ths of an inch																			
	3/64 by 3/64					4/64 by 4/64					5/64 by 5/64					6/64 by 6/64				
	Capacitance			Susceptance to neutral		Capacitance			Susceptance to neutral		Capacitance			Susceptance to neutral		Capacitance			Susceptance to neutral	
	C 1	C 12	C 1 & 2	25 cycles	60 cycles	C 1	C 12	C 1 & 2	25 cycles	60 cycles	C 1	C 12	C 1 & 2	25 cycles	60 cycles	C 1	C 12	C 1 & 2	25 cycles	60 cycles
500,000	0.680	−0.217	0.448	141	337	0.613	−0.175	0.394	124	297	0.555	−0.154	0.354	111	267	0.505	−0.137	0.321	101	242
450,000	0.667	−0.197	0.432	136	325	0.590	−0.169	0.379	119	286	0.538	−0.149	0.343	108	259	0.488	−0.130	0.309	97	233
400,000	0.657	−0.194	0.425	133	320	0.570	−0.159	0.364	114	274	0.517	−0.142	0.329	103	248	0.475	−0.125	0.300	94	226
350,000	0.640	−0.189	0.414	130	313	0.560	−0.158	0.359	113	270	0.506	−0.138	0.322	101	242	0.460	−0.119	0.289	91	218
300,000	0.606	−0.176	0.391	123	294	0.545	−0.153	0.349	110	263	0.490	−0.131	0.310	97	234	0.446	−0.116	0.281	88	212
250,000	0.590	−0.171	0.380	120	286	0.518	−0.142	0.330	104	249	0.468	−0.125	0.296	93	223	0.427	−0.109	0.268	84	202
0,000	0.570	−0.160	0.365	111	265	0.500	−0.134	0.317	100	239	0.445	−0.115	0.280	88	211	0.407	−0.103	0.255	80	192
000	0.535	−0.147	0.341	107	257	0.475	−0.125	0.300	94	226	0.420	−0.107	0.262	82	198	0.384	−0.095	0.239	75	180
00	0.513	−0.140	0.327	103	246	0.447	−0.116	0.281	88	212	0.398	−0.101	0.249	78	187	0.364	−0.088	0.226	71	170
0	0.494	−0.123	0.308	97	232	0.422	−0.107	0.264	83	199	0.374	−0.090	0.232	73	175	0.342	−0.081	0.211	66	159
1	0.462	−0.119	0.290	91	219	0.398	−0.099	0.248	78	187	0.356	−0.086	0.221	69	167	0.323	−0.074	0.198	62	149
2	0.420	−0.107	0.263	83	198	0.373	−0.091	0.232	73	175	0.332	−0.077	0.203	64	153	0.305	−0.070	0.187	59	141
3	0.402	−0.101	0.251	79	189	0.352	−0.084	0.218	69	165	0.314	−0.072	0.193	61	145	0.284	−0.062	0.173	54	131
4	0.378	−0.100	0.239	75	180	0.330	−0.077	0.203	64	153	0.295	−0.066	0.180	57	136	0.270	−0.059	0.164	52	124
6	0.342	−0.081	0.211	66	159	0.301	−0.063	0.182	57	137	0.264	−0.056	0.160	50	121	0.239	−0.050	0.144	45	108

Area in circular mils B & S No.	7/64 by 7/64					8/64 by 8/64					9/64 by 9/64					10/64 by 10/64				
	Capacitance			Susceptance to neutral		Capacitance			Susceptance to neutral		Capacitance			Susceptance to neutral		Capacitance			Susceptance to neutral	
	C 1	C 12	C 1 & 2	25 cycles	60 cycles	C 1	C 12	C 1 & 2	25 cycles	60 cycles	C 1	C 12	C 1 & 2	25 cycles	60 cycles	C 1	C 12	C 1 & 2	25 cycles	60 cycles
500,000	0.468	−0.124	0.296	93	224	0.435	−0.115	0.275	86	207	0.410	−0.104	0.257	81	193	0.392	−0.197	0.244	77	184
450,000	0.454	−0.119	0.286	90	216	0.427	−0.107	0.267	84	201	0.405	−0.103	0.254	79	191	0.380	−0.093	0.236	74	178
400,000	0.442	−0.116	0.279	88	210	0.415	−0.105	0.260	82	196	0.392	−0.099	0.245	77	184	0.368	−0.090	0.229	72	173
350,000	0.426	−0.108	0.267	84	201	0.398	−0.099	0.248	78	187	0.380	−0.093	0.236	74	178	0.358	−0.087	0.222	70	167
300,000	0.415	−0.105	0.260	82	196	0.390	−0.096	0.243	76	183	0.365	−0.089	0.227	71	171	0.348	−0.081	.215	68	162
250,000	0.400	−0.101	0.250	79	188	0.370	−0.089	0.229	72	173	0.352	−0.087	0.219	69	165	0.332	−0.078	0.205	65	155
0,000	0.380	−0.094	0.237	75	178	0.354	−0.085	0.220	69	166	0.334	−0.076	0.205	64	155	0.316	−0.073	0.194	61	146
000	0.358	−0.086	0.222	70	168	0.332	−0.079	0.205	64	155	0.315	−0.073	0.194	61	146	0.296	−0.066	0.181	57	136
00	0.336	−0.080	0.208	65	157	0.313	−0.071	0.192	60	145	0.295	−0.067	0.181	57	136	0.278	−0.061	0.169	53	127
0	0.317	−0.073	0.195	61	147	0.293	−0.065	0.179	56	135	0.279	−0.061	0.170	54	128	0.263	−0.056	0.159	50	120
1	0.299	−0.068	0.183	58	138	0.280	−0.061	0.170	54	128	0.261	−0.056	0.158	50	119	0.247	−0.055	0.151	47	114
2	0.279	−0.062	0.170	54	128	0.264	−0.056	0.160	50	121	0.247	−0.052	0.150	47	113	0.233	−0.048	0.140	44	106
3	0.264	−0.056	0.160	50	121	0.248	−0.052	0.150	47	113	0.232	−0.048	0.140	44	106	0.222	−0.044	0.133	42	100
4	0.250	−0.053	0.151	47	114	0.233	−0.048	0.140	44	106	0.221	−0.045	0.133	42	100	0.210	−0.041	0.125	39	94
6	0.221	−0.045	0.133	42	100	0.209	−0.041	0.125	39	94	0.198	−0.037	0.177	37	88	0.188	−0.036	0.112	35	85

TABLE XXVII.—CAPACITANCE AND SUSCEPTANCE PER MILE OF THREE-CONDUCTOR, PAPER-INSULATED CABLES.—(*Continued*)

Area in circular mils B & S No.	Insulation thickness in 64ths of an inch																			
	11/64 by 11/64					12/64 by 12/64					13/64 by 13/64					14/64 by 14/64				
	Capacitance			Susceptance to neutral		Capacitance			Susceptance to neutral		Capacitance			Susceptance to neutral		Capacitance			Susceptance to neutral	
	C 1	C 12	C 1 & 2	25 cycles	60 cycles	C 1	C 12	C 1 & 2	25 cycles	60 cycles	C 1	C 12	C 1 & 2	25 cycles	60 cycles	C 1	C 12	C 1 & 2	25 cycles	60 cycles
500,000	0.371	−0.089	0.230	72	173	0.355	−0.085	0.220	69	166	0.343	−0.082	0.212	67	160	0.329	−0.078	0.203	64	153
450,000	0.364	−0.087	0.225	71	170	0.352	−0.085	0.218	68	164	0.332	−0.078	0.205	64	155	0.321	−0.075	0.198	62	149
400,000	0.356	−0.085	0.220	69	166	0.338	−0.080	0.209	66	157	0.326	−0.076	0.201	63	152	0.310	−0.071	0.190	60	143
350,000	0.340	−0.080	0.210	66	158	0.328	−0.077	0.202	63	152	0.317	−0.073	0.195	61	147	0.300	−0.068	0.184	58	139
300,000	0.329	−0.078	0.203	64	153	0.313	−0.071	0.192	60	145	0.303	−0.069	0.186	59	140	0.290	−0.065	0.177	56	133
250,000	0.316	−0.072	0.199	63	150	0.98	−0.068	0.183	58	138	0.288	−0.064	0.176	55	133	0.276	−0.061	0.168	53	127
0,000	0.302	−0.069	0.185	58	140	0.235	−0.067	0.176	55	133	0.278	−0.061	0.169	53	127	0.264	−0.056	0.160	50	121
000	0.282	−0.061	0.171	54	129	0.271	−0.060	0.165	52	124	0.261	−0.056	0.158	50	119	0.251	−0.053	0.152	48	115
00	0.267	−0.058	0.162	51	122	0.255	−0.054	0.154	48	116	0.247	−0.052	0.150	47	113	0.237	−0.048	0.142	45	107
0	0.250	−0.053	0.151	48	114	0.241	−0.050	0.145	46	109	0.233	−0.048	0.140	44	106	0.222	−0.044	0.133	42	100
1	0.237	−0.050	0.143	45	108	0.228	−0.047	0.137	43	103	0.220	−0.044	0.132	42	100	0.212	−0.042	0.127	40	96
2	0.222	−0.045	0.133	42	100	0.216	−0.044	0.130	41	98	0.208	−0.041	0.124	39	94	0.199	−0.039	0.118	37	89
3	0.212	−0.042	0.127	40	96	0.204	−0.039	0.121	38	91	0.195	−0.037	0.116	36	88	0.190	−0.036	0.113	36	85
4	0.201	−0.039	0.120	38	91	0.192	−0.037	0.114	36	86	0.186	−0.034	0.110	35	83	0.180	−0.033	0.106	33	80
6	0.181	−0.033	0.107	34	81	0.174	−0.031	0.102	32	77	0.168	−0.030	0.099	31	75	0.163	−0.029	0.096	30	73

Area in circular mils B & S No.	16/64 by 16/64					18/64 by 18/64					20/64 by 20/64					22/64 by 22/64				
	Capacitance			Susceptance to neutral		Capacitance			Susceptance to neutral		Capacitance			Susceptance to neutral		Capacitance			Susceptance to neutral	
	C 1	C 12	C 1 & 2	25 cycles	60 cycles	C 1	C 12	C 1 & 2	25 cycles	60 cycles	C 1	C 12	C 1 & 2	25 cycles	60 cycles	C 1	C 12	C 1 & 2	25 cycles	60 cycles
500,000	0.308	−0.071	0.189	59	143	0.288	−0.065	0.176	55	133	0.276	−0.061	0.168	53	127	0.263	−0.057	0.160	50	121
450,000	0.302	−0.069	0.185	58	140	0.282	−0.062	0.172	54	130	0.269	−0.058	0.163	51	123	0.255	−0.054	0.154	48	116
400,000	0.292	−0.066	0.179	56	135	0.276	−0.060	0.168	53	127	0.260	−0.055	0.157	50	118	0.249	−0.053	0.151	47	113
350,000	0.282	−0.061	0.171	54	129	0.266	−0.057	0.161	51	121	0.252	−0.053	0.152	48	115	0.240	−0.049	0.144	45	108
300,000	0.271	−0.059	0.165	52	125	0.256	−0.054	0.155	49	117	0.242	−0.050	0.146	46	110	0.232	−0.047	0.139	44	105
250,000	0.260	−0.055	0.157	49	118	0.244	−0.051	0.147	46	111	0.231	−0.048	0.139	44	105	0.222	−0.044	0.133	42	100
0,000	0.248	−0.052	0.150	47	113	0.233	−0.049	0.141	44	106	0.222	−0.044	0.133	42	100	0.211	−0.041	0.126	40	96
000	0.234	−0.048	0.141	44	106	0.221	−0.044	0.132	42	100	0.211	−0.041	0.126	40	95	0.200	−0.038	0.119	38	90
00	0.222	−0.044	0.133	42	100	0.209	−0.041	0.125	39	94	0.199	−0.038	0.118	37	89	0.191	−0.036	0.113	36	85
0	0.210	−0.041	0.125	39	94	0.199	−0.038	0.118	37	89	0.188	−0.036	0.112	35	85	0.180	−0.030	0.105	33	79
1	0.198	−0.038	0.118	37	89	0.188	−0.035	0.111	35	84	0.181	−0.034	0.107	33	81	0.172	−0.030	0.101	32	76
2	0.190	−0.036	0.113	36	86	0.179	−0.032	0.105	33	79	0.170	−0.030	0.100	32	76	0.163	−0.029	0.096	30	73
3	0.179	−0.034	0.107	34	81	0.171	−0.031	0.101	32	76	0.162	−0.028	0.095	30	72	0.155	−0.026	0.090	28	68
4	0.170	−0.030	0.100	32	76	0.162	−0.027	0.094	30	71	0.154	−0.026	0.090	28	68	0.148	−0.025	0.086	27	65
6	0.154	−0.025	0.089	28	67	0.147	−0.024	0.085	27	64	0.141	−0.023	0.082	26	62	0.136	−0.021	0.978	25	59

results calculated by the above formulas are given in Fig. *C*. It will be seen that in all cases these calculated results are less than the corresponding test results, the discrepancy being greater as the conductor becomes larger and the separation less. The differences vary from zero to as much as 11 per cent for the largest cable, at the minimum spacing shown. The discrepancy is greatest with the minimum thickness of insulation. Since such cables would be used only for low-voltage service, the charging current would be small and consequently this error would probably be of little importance. For 6,600-volt cables the results by the formula would seem to be approximately 5 per cent too low.

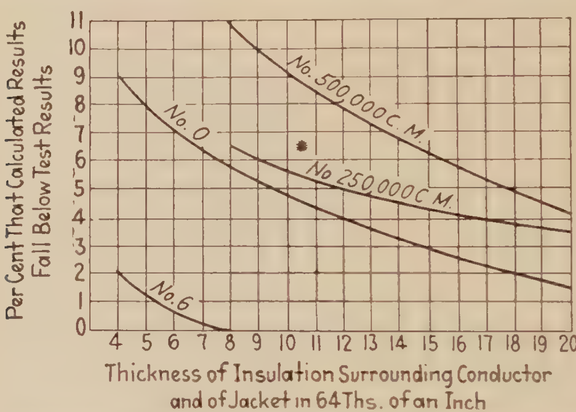


FIG. *C*.—Comparison of calculated and measured capacitances. Tests made on three conductor paper insulated cables, K = 3.5.

The cause of the discrepancy between the formula and test results is as follows: In order to obtain a mathematical solution, Russell found it necessary to make certain approximations to the true physical conditions. Thus, the resulting mathematical formula cannot give exact results. The approximation made by Russell is very close to the actual physical fact where the conductors are small compared with the insulation thickness, but it is not very close where the conductors are large compared with the insulation.

Charging Kva. Table XXVIII.—Table XXVIII contains values for charging current (expressed in kva., three-phase) for three-conductor, paper-insulated cables, both 25 and 60 cycles, based upon a value for *K* of 3.5. For other values of *K*, the table values would vary in proportion. For other thicknesses of insulation, the kva. values would vary as the susceptance values cor-

TABLE XXVIII.—THREE-PHASE CHARGING KVA. PER MILE OF THREE-PHASE CIRCUIT OF THREE-CONDUCTOR, PAPER-INSULATED CABLES.

25 cycles

Area in circular mils B & S No.	Charging kva. per mile (expressed in kva. three-phase) for paper-insulated, three-conductor cables based upon a value for *K* of 3.5 and upon a thickness of insulation surrounding the conductors and of the jacket indicated									
	220 volts	440 volts	550 volts	1,100 volts	2,200 volts	4,400 volts	6,000 volts		6,600 volts		6,900 volts
	4/64	4/64	4/64	5/64	6/64	8/64	10/64	14/64	10/64	14/64	10/64
500,000	0.00600	0.0240	0.0376	0.134	0.488	1.66	2.76	2.26	3.35	2.79	3.66
450,000	0.00575	0.0230	0.0360	0.131	0.469	1.62	2.66	2.22	3.22	2.70	3.52
400,000	0.00550	0.0220	0.0346	0.125	0.455	1.58	2.58	2.15	3.13	2.61	3.42
350,000	0.00545	0.0218	0.0342	0.122	0.440	1.51	2.51	2.08	3.04	2.52	3.33
300,000	0.00532	0.0213	0.0333	0.117	0.425	1.47	2.44	2.01	2.96	2.44	3.23
250,000	0.00502	0.0201	0.0315	0.113	0.406	1.39	2.33	1.90	2.83	2.31	3.09
0,000	0.00483	0.0193	0.0303	0.106	0.387	1.33	2.19	1.79	2.65	2.18	2.90
000	0.00454	0.0182	0.0285	0.099	0.363	1.24	2.04	1.72	2.48	2.09	2.71
00	0.00424	0.0170	0.0266	0.094	0.343	1.16	1.90	1.61	2.31	1.96	2.52
0	0.00400	0.0160	0.0250	0.0883	0.319	1.08	1.79	1.51	2.18	1.83	2.37
1	0.00376	0.0151	0.0236	0.0836	0.300	1.04	1.68	1.43	2.05	1.74	2.23
2	0.00352	0.0141	0.0221	0.0775	0.286	0.965	1.58	1.38	1.92	1.61	2.09
3	0.00333	0.0133	0.0209	0.0740	0.261	0.908	1.51	1.29	1.83	1.57	2.00
4	0.00309	0.0124	0.0194	0.0690	0.252	0.850	1.40	1.18	1.70	1.44	1.85
6	0.00275	0.0110	0.0173	0.0605	0.218	0.755	1.26	1.08	1.52	1.31	1.66

25 cycles

Area in circular mils B & S No.	10,000 volts	11,000 volts		13,200 volts		16,500 volts	20,000 volts		22,000 volts	25,000 volts	
	12/64	12/64	14/64	12/64	16/64	14/64	16/64	18/64	18/64	18/64	20/64
500,000	6.93	8.35	7.77	12.00	10.25	17.35	23.6	22.0	26.6	34.5	33.3
450,000	6.83	8.23	7.50	11.80	10.10	16.80	23.3	21.6	26.1	33.8	32.0
400,000	6.62	7.98	7.26	11.50	9.75	16.25	22.4	21.2	25.6	33.2	31.4
350,000	6.33	7.62	7.02	10.95	9.40	15.75	21.6	20.4	24.6	32.0	30.1
300,000	6.02	7.27	6.78	10.45	9.05	15.20	20.8	19.6	23.7	30.7	28.8
250,000	5.82	7.02	6.42	10.10	8.52	14.40	19.6	18.4	22.2	28.8	27.6
0,000	5.53	6.66	6.05	9.56	8.17	13.55	18.8	17.6	21.3	27.6	26.4
000	5.23	6.30	5.82	9.05	7.65	13.05	17.6	16.8	20.3	26.3	25.1
00	4.82	5.80	5.45	8.36	7.30	12.25	16.8	15.6	18.8	24.4	23.2
0	4.62	5.57	5.09	8.00	6.78	11.40	15.6	14.8	17.8	23.2	22.0
1	4.32	5.21	4.84	7.48	6.43	10.85	14.8	14.0	16.9	21.9	20.7
2	4.12	4.97	4.48	7.13	6.26	10.05	14.4	13.2	15.9	20.7	20.1
3	3.82	4.60	4.36	6.60	5.92	9.78	13.6	12.8	15.5	20.1	18.8
4	3.62	4.36	4.00	6.27	5.57	8.95	12.8	12.0	14.5	18.8	17.6
6	3.22	3.87	3.63	5.57	4.87	8.15	11.2	10.8	13.1	16.9	16.3

responding to the thickness of insulation (see Table XXVII). In some cases, such, for instance, as grounded neutral systems, the thickness of insulation of the jacket may be less than that surrounding the conductors. In such cases it might be desirable to calculate the susceptance and charging current, if accurate results were desired. The values for charging current corresponding to

TABLE XXVIII.—THREE-PHASE CHARGING KVA. PER MILE OF THREE-PHASE CIRCUIT OF THREE-CONDUCTOR, PAPER-INSULATED CABLES.—(*Continued*)

60 cycles

Area in circular mils B & S No.	Charging kva. per mile (expressed in kva. three-phase) for paper-insulated, three-conductor cables based upon a value for *K* of 3.5 and upon a thickness of insulation surrounding the conductors and of the jacket indicated									
	220 volts	440 volts	550 volts	1,100 volts	2,200 volts	4,400 volts	6,000 volts		6,600 volts		6,900 volts
	4/64	4/64	4/64	5/64	6/64	8/64	10/64	14/64	10/64	14/64	10/64
500,000	0.0143	0.0574	0.0900	0.323	1.17	4.00	6.58	5.49	8.00	6.65	8.73
450,000	0.0138	0.0554	0.0858	0.313	1.13	3.88	6.40	5.33	7.75	6.48	8.46
400,000	0.0132	0.0530	0.0830	0.301	1.09	3.79	6.20	5.13	7.53	6.22	8.22
350,000	0.0131	0.0523	0.0818	0.292	1.05	3.61	5.98	4.98	7.25	6.07	7.93
300,000	0.0127	0.0510	0.0798	0.283	1.02	3.54	5.80	4.78	7.05	5.80	7.70
250,000	0.0120	0.0483	0.0755	0.270	0.975	3.35	5.55	4.56	6.75	5.52	7.37
0,000	0.0115	0.0463	0.0725	0.255	0.925	3.22	5.24	4.33	6.35	5.26	6.93
000	0.0109	0.0437	0.0685	0.240	0.870	3.00	4.88	4.12	5.92	5.00	6.47
00	0.0102	0.0410	0.0643	0.226	0.820	2.80	4.55	3.84	5.52	4.65	6.03
0	0.0096	0.0385	0.0602	0.212	0.768	2.61	4.30	3.59	5.22	4.35	5.70
1	0.0090	0.0362	0.0566	0.202	0.720	2.48	4.08	3.44	4.95	4.17	5.42
2	0.0084	0.0339	0.0530	0.185	0.680	2.34	3.80	3.19	4.60	3.87	5.04
3	0.0080	0.0320	0.0500	0.176	0.632	2.18	3.59	3.05	4.35	3.70	4.75
4	0.0074	0.0296	0.0465	0.165	0.600	2.05	3.37	2.87	4.08	3.48	4.46
6	0.0066	0.0265	0.0415	0.147	0.522	1.82	3.05	2.62	3.70	3.17	4.05

60 cycles

Area in circular mils B & S No.	10,000 volts	11,000 volts		13,200 volts		16,500 volts	20,000 volts		22,000 volts	25,000 volts	
	12/64	12/64	14/64	12/64	16/64	14/64	16/64	18/64	18/64	18/64	20/64
500,000	16.7	20.1	18.5	28.9	24.9	41.5	57.3	53.3	64.2	83.3	79.5
450,000	16.5	19.8	18.1	28.5	24.4	40.3	56.0	52.0	52.7	81.5	77.0
400,000	15.8	19.0	17.3	27.2	23.5	38.8	54.0	50.9	61.3	79.5	74.0
350,000	15.3	18.4	15.8	26.4	22.4	37.6	51.6	48.5	58.3	75.8	72.2
300,000	14.6	17.6	16.1	25.2	21.8	36.0	50.0	46.8	56.5	73.3	65.0
250,000	13.9	16.7	15.4	24.0	20.5	34.5	47.3	44.3	53.6	69.5	65.7
0,000	13.4	16.1	14.7	23.2	19.6	32.8	45.3	42.5	51.2	66.5	62.7
000	12.5	15.0	13.9	21.6	18.4	31.2	42.5	40.0	48.3	62.7	59.5
00	11.7	14.1	13.0	20.2	17.4	29.0	40.0	37.6	45.4	59.0	55.7
0	11.0	13.2	12.1	18.9	16.3	27.2	37.6	35.7	43.0	55.8	53.3
1	10.4	12.5	11.6	17.9	15.5	26.0	35.6	33.6	40.5	52.5	50.7
2	9.85	11.9	10.8	17.0	14.9	24.1	34.5	31.7	38.2	49.5	47.6
3	9.15	11.0	10.3	15.8	14.1	23.0	32.4	30.4	37.6	47.6	45.2
4	8.65	10.4	9.7	15.0	13.2	21.7	30.4	28.4	34.3	44.5	42.6
6	7.75	9.3	8.8	13.4	11.7	19.8	26.9	25.6	30.9	40.2	38.9

two thicknesses of insulation are included for some of the commonly employed transmission voltages.

These kva. values were calculated by using the values for susceptance in Table XXVII which, in turn, were derived from the capacitance in the same table obtained by Eqs. (70) and (71). Thus, a 350,000-cir.-mil cable with $^{10}/_{64}$- and $^{10}/_{64}$-in. paper insulation has a 60-cycle susceptance to neutral of 167 micromhos per

mile. Since the charging current in amperes to neutral equals the susceptance to neutral $\times$ volts to neutral $\times 10^{-6}$ and assuming 6,600 volts, three phase between conductors,

$$167 \times \frac{6,600}{1.73} \times 10^{-6} = 0.637 \text{ amperes to neutral.}$$

Charging kva. = $0.637 \times 3815 \times 3 = 7.25$ kva.,
as indicated in Table XXVIII.

Values for K.—The capacitance of any cable depends upon the dielectric constant of the insulating material and a dimension term or form factor. The dielectric constant should be determined from actual cables and not from samples of material. The usual range in value for K is given below.

	Value of K
Impregnated paper	3.0 to 4.0
Varnished cambric	4.0 to 6.0
Rubber	4.0 to 9.0

All values in Tables XXVII and XXVIII are based upon a value of K of 3.5. For all other values of K all table values will vary in the same proportion as their K values. The actual value of permitivity of most paper insulation runs about 10 per cent less than the value 3.5 which has been used in calculating the accompanying table values. The true a.-c. capacitance is always considerably lower than the capacitance measured with ballistic galvanometer.

REFERENCES

Atkinson, "The Dielectric Field in an Electric Power Cable," *Trans. Am. Inst. Elec. Eng.*, June, 1919.

Atkinson, "The Current Carrying Capacity of Lead Covered Cables," *J. Am. Inst. Elec. Eng.*, September, 1920.

Atkinson and Fisher, "Current and Rating of Electric Cables," *Trans Am. Inst. Elec. Eng.*, p. 325, 1913.

Coyle and Howe, "Electric Cables," London, England.

Del Mar, W. S., "Electric Power Conductors."

Dushman, "The Heating of Cables Carrying Current," *Trans. Am. Inst. Elec. Eng.*, p. 333, 1913.

Imlay, "Effect of Moisture in the Earth on Temperature of Underground Cables," *Trans. Am. Inst. Elec. Eng.*, Part I, p. 233, 1915.

Melsom and Booth, "The Heating of Cables with Current," *J. Am. Inst. Elec. Eng.*, vol. 47, 1911.

Powell, Richard A., "Temperature Rise of Insulated Lead Covered Cables," *Trans. Am. Inst. Elec. Eng.*, Part II, p. 1017, 1916.

Rickets, "The Restoration of Service after a Necessary Interruption," *Trans. Am. Inst. Elec. Eng.*, Part II, p. 635, 1916.

GENERAL CABLE DATA

General Electric Company—Impregnated Paper-insulated, Lead-sheathed Cables—General Data
Minimum recommended thickness of paper and lead, single-conductor cable

Size conduit		Thickness in inches		Kv. test, 5 min.	Maximum diameter over lead in inches	Approximate net weight in pounds per 1,000 ft.	Thickness in inches		Kv. test, 5 min.	Maximum diameter over lead in inches	Approximate net weight in pounds per 1,000 ft.
AWG	Sq. mm.	Insulation	Lead				Insulation	Lead			
		Maximum working pressure—500 volts a.-c. delta 660 volts a.-c. *Y*					750 volts d.-c. railway—2,500 volts a.-c. delta 3,300 volts a.-c. *Y*				
8	8.4	0.065	0.065	4	0.415	410	0.100	0.065	10	0.486	490
6	13.3	0.065	0.065	4	0.452	480	0.100	0.070	10	0.534	560
4	21.2	0.065	0.065	4	0.502	580	0.100	0.070	10	0.583	670
2	33.6	0.065	0.070	4	0.573	740	0.100	0.070	10	0.644	810
1	42.4	0.065	0.070	4	0.614	830	0.100	0.075	10	0.695	1,070
1/0	53.5	0.065	0.070	4	0.655	1,090	0.100	0.075	10	0.736	1,210
2/0	67.4	0.065	0.075	4	0.713	1,220	0.100	0.075	10	0.784	1,350
3/0	85.0	0.065	0.075	4	0.765	1,600	0.100	0.080	10	0.846	1,530
4/0	107.0	0.065	0.080	4	0.814	1,810	0.100	0.080	10	0.905	1,760
Circular inch											
0.25	127.0	0.075	0.080	4	0.904	2,050	0.100	0.080	10	0.954	2,090
0.30	152.0	0.075	0.080	4	0.965	2,250	0.100	0.085	10	1.025	2,410
0.35	177.0	0.075	0.085	4	1.020	2,450	0.100	0.085	10	1.070	2,650
0.40	203.0	0.075	0.085	4	1.070	2,750	0.100	0.095	10	1.140	2,890
0.45	228.0	0.075	0.085	4	1.120	3,050	0.100	0.095	10	1.190	3,120
0.50	253.0	0.075	0.095	4	1.180	3,300	0.100	0.095	10	1.230	3,340
0.60	304.0	0.075	0.095	4	1.260	3,810	0.100	0.095	10	1.310	3,880
0.70	355.0	0.075	0.095	4	1.330	4,190	0.100	0.095	10	1.380	4,250
0.75	380.0	0.075	0.095	4	1.365	4,400	0.100	0.095	10	1.415	4,500
0.80	405.0	0.075	0.095	4	1.405	4,580	0.110	0.100	10	1.485	4,650
1.00	507.0	0.075	0.100	4	1.535	5,750	0.110	0.105	10	1.615	5,850
1.25	633.0	0.075	0.105	4	1.710	6,810	0.110	0.110	10	1.790	6,960
1.50	760.0	0.075	0.110	4	1.830	7,850	0.110	0.115	10	1.910	8,000
1.75	887.0	0.075	0.115	4	1.975	8,000	0.110	0.115	10	2.050	9,050
2.00	1,013.0	0.075	0.120	4	2.065	10,300	0.110	0.120	10	2.130	10,500

		Maximum working pressure—5,000 volts a.-c. delta 6,600 volts a.-c. Y					7,500 volts a.-c. delta 10,000 volts a.-c. Y				
AWG				5 min.					15 min.		
8	8.4	0.160	0.070	17	0.619	810					
6	13.3	0.160	0.070	17	0.656	900	0.200	0.075	24.5	0.747	1,120
4	21.2	0.160	0.075	17	0.715	1,020	0.200	0.080	24.5	0.807	1,240
2	33.6	0.160	0.075	17	0.776	1,190	0.200	0.080	24.5	0.868	1,600
1	42.4	0.160	0.080	17	0.828	1,310	0.200	0.080	24.5	0.910	1,710
1/0	53.5	0.160	0.080	17	0.870	1,590	0.200	0.080	24.5	0.952	1,900
2/0	67.4	0.160	0.080	17	0.916	1,780	0.200	0.085	24.5	1.010	2,050
3/0	85.0	0.160	0.085	17	0.979	2,010	0.200	0.085	24.5	1.060	2,210
4/0	107.0	0.160	0.085	17	1.040	2,250	0.200	0.095	24.5	1.140	2,550
Circular inch											
0.25	127.0	0.160	0.085	17	1.090	2,460	0.200	0.095	24.5	1.190	2,760
0.30	152.0	0.160	0.095	17	1.170	2,710	0.200	0.095	24.5	1.250	3,010
0.35	177.0	0.160	0.095	17	1.220	2,950	0.200	0.095	24.5	1.300	3,260
0.40	203.0	0.160	0.095	17	1.260	3,200	0.200	0.095	24.5	1.340	3,510
0.45	228.0	0.160	0.095	17	1.310	3,500	0.200	0.095	24.5	1.390	3,750
0.50	253.0	0.160	0.095	17	1.350	3,700	0.200	0.100	24.5	1.440	3,980
0.60	304.0	0.160	0.100	17	1.440	4,210	0.200	0.100	24.5	1.520	4,430
0.70	355.0	0.160	0.100	17	1.515	4,640	0.200	0.105	24.5	1.610	5,260
0.75	380.0	0.160	0.100	17	1.550	5,060	0.200	0.105	24.5	1.640	5,480
0.80	405.0	0.160	0.105	17	1.600	5,440	0.200	0.105	24.5	1.680	5,710
1.00	507.0	0.160	0.105	17	1.715	6,300	0.200	0.110	24.5	1.810	6,600
1.25	633.0	0.160	0.110	17	1.890	7,350	0.200	0.115	24.5	1.980	7,660
1.50	760.0	0.160	0.115	17	2.020	8,400	0.200	0.125	24.5	2.220	9,220
1.75	887.0	0.160	0.120	17	2.060	9,860	0.200	0.125	24.5	2.250	10,260
2.00	1,013.0	0.160	0.125	17	2.250	10,800	0.200	0.125	24.5	2.330	11,280

GENERAL ELECTRIC COMPANY—IMPREGNATED PAPER-INSULATED, LEAD-SHEATHED CABLES—GENERAL DATA.—(*Continued*)

Size conduit		Thickness in inches		Kv. test, 5 min.	Maximum diameter over lead in inches	Approximate net weight in pounds per 1,000 ft.	Thickness in inches		Kv. test, 5 min.	Maximum diameter over lead in inches	Approximate net weight in pounds per 1,000 ft.
AWG	Sq. mm.	Insulation	Lead				Insulation	Lead			
		Maximum working pressure—12,500 volts a.-c. delta 16,600 volts a.-c. *Y*					15,000 volts a.-c. delta 20,000 volts a.-c. *Y*				
				15 min.					15 min.		
2	33.6	0.290	0.085	39.5	1.060	1,700	0.330	0.095	47	1.165	2,280
1	42.4	0.290	0.085	39.5	1.100	2,100	0.330	0.095	47	1.210	2,420
1/0	53.5	0.290	0.095	39.5	1.170	2,200	0.330	0.095	47	1.250	2,570
2/0	67.4	0.290	0.095	39.5	1.210	2,460	0.330	0.095	47	1.292	2,750
3/0	85.0	0.290	0.095	39.5	1.265	2,680	0.330	0.095	47	1.345	2,950
4/0	107.0	0.290	0.095	39.5	1.320	2,930	0.330	0.095	47	1.405	3,220
Circular inch											
0.25	127.0	0.290	0.095	39.5	1.370	3,140	0.330	0.100	47	1.460	3,440
0.30	152.0	0.290	0.100	39.5	1.445	3,420	0.330	0.100	47	1.525	3,720
0.35	177.0	0.290	0.100	39.5	1.490	3,660	0.330	0.100	47	1.575	3,960
0.40	203.0	0.290	0.100	39.5	1.540	3,900	0.330	0.105	47	1.630	4,620
0.45	228.0	0.290	0.100	39.5	1.590	4,340	0.330	0.105	47	1.680	4,880
0.50	253.0	0.290	0.105	39.5	1.640	4,780	0.330	0.105	17	1.720	5,130
0.60	304.0	0.290	0.105	39.5	1.720	5,270	0.330	0.110	47	1.790	5,620
0.70	355.0	0.290	0.110	39.5	1.800	5,750	0.330	0.115	47	1.890	6,110
0.75	380.0	0.290	0.110	39.5	1.830	5,970	0.330	0.115	47	1.925	6,330
0.80	405.0	0.290	0.110	39.5	1.870	6,180	0.330	0.115	47	1.965	6,560
1.00	507.0	0.290	0.115	39.5	2.000	7,100	0.330	0.120	47	2.100	7,480
1.25	633.0	0.290	0.120	39.5	2.180	8,780	0.330	0.125	47	2.270	9,290
1.50	760.0	0.290	0.125	39.5	2.300	9,810	0.330	0.130	47	2.390	10,300
1.75	887.0	0.290	0.130	39.5	2.440	11,010	0.330	0.135	47	2.540	10,500
2.00	1,013.0	0.290	0.135	39.5	2.530	11,940	0.330	0.135	47	12.620	12,450

		Maximum working pressure—20,000 volts a.-c delta 25,000 volts a.-c. Y					25,000 volts a.-c. delta 33,000 volts a.-c. Y				
2	33.6	0.420	0.095	62	1.350	2,630					
1	42.4	0.420	0.095	62	1.390	2,720	0.520	0.105	77	1.590	3,050
1/0	53.5	0.420	0.100	62	1.440	2,880	0.520	0.105	77	1.635	3,330
2/0	67.4	0.420	0.100	62	1.485	3,060	0.520	0.105	77	1.680	3,410
3/0	85.0	0.420	0.100	62	1.540	3,280	0.520	0.110	77	1.745	3,650
4/0	107.0	0.420	0.105	62	1.610	3,940	0.520	0.110	77	1.800	4,640
Circular inch											
0.25	127.0	0.420	0.105	62	1.660	4,170	0.520	0.110	77	1.850	4,980
0.30	152.0	0.420	0.105	62	1.720	4,470	0.520	0.115	77	1.920	5,300
0.35	177.0	0.420	0.110	62	1.780	4,740	0.520	0.115	77	1.970	5,600
0.40	203.0	0.420	0.110	62	1.820	4,990	0.520	0.115	77	2.020	5,920
0.45	228.0	0.420	0.110	62	1.870	5,250	0.520	0.115	77	2.070	6,210
0.50	253.0	0.420	0.115	62	1.920	5,500	0.520	0.120	77	2.120	6,540
0.60	304.0	0.420	0.115	62	2.000	6,010	0.520	0.125	77	2.210	6,960
0.70	355.0	0.420	0.120	62	2.090	6,500	0.520	0.125	77	2.280	7,400
0.75	380.0	0.420	0.120	62	2.120	6,780	0.520	0.125	77	2.310	7,680
0.80	405.0	0.420	0.125	62	2.170	7,490	0.520	0.130	77	2.360	8,500
1.00	507.0	0.420	0.125	62	2.290	8,550	0.520	0.130	77	2.480	9,730
1.25	633.0	0.420	0.130	62	2.460	9,760	0.520	0.135	77	2.660	10,300
1.50	760.0	0.420	0.135	62	2.580	10,740					
1.75	887.0	0.420	0.140	62	2.730	12,000					
2.00	1,013.0	0.420	0.145	62	2.820	12,960					

IMPREGNATED PAPER-INSULATED, LEAD-SHEATHED CABLES—GENERAL DATA

Minimum recommended thickness of paper and lead, three-conductor cable

Size conduit		Cylindrical conductors						Semi-sector conductors		
		Thickness in inches								
		Insulation								
AWG	Sq. mm.	Between conductors	Between conductor and lead	Lead	Kv. test, 5 min.	Maximum diameter over lead in inches	Approximate net weight in pounds per 1,000 ft.	Thickness lead in inches	Maximum diameter over lead in inches	Approximate net weight in pounds per 1,000 ft.
Maximum working pressure—750 volts a.c. Y-circuit grounded neutral										
8	8.4	0.080	0.055	0.075	5	0.695	1,080			
6	13.3	0.080	0.055	0.075	5	0.775	1,360			
4	21.2	0.080	0.055	0.080	5	0.895	1,790			
2	33.6	0.080	0.055	0.085	5	1.040	2,280			
1	42.4	0.080	0.055	0.085	5	1.130	2,570	0.085	1.020	2,000
1/0	53.5	0.080	0.055	0.090	5	1.230	3,050	0.085	1.095	2,360
2/0	67.4	0.080	0.055	0.095	5	1.345	3,630	0.090	1.195	3,200
3/0	85.0	0.080	0.055	0.100	5	1.470	4,220	0.090	1.300	3,510
4/0	107.0	0.080	0.055	0.105	5	1.610	5,150	0.095	1.400	4,360
Circular inch										
0.25	127.0	0.100	0.070	0.110	5	1.780	5,800	0.100	1.565	5,360
0.30	152.0	0.100	0.070	0.115	5	1.930	6,540	0.105	1.670	5,630
0.35	177.0	0.100	0.070	0.115	5	2.030	7,710	0.105	1.765	6,950
0.40	203.0	0.100	0.070	0.120	5	2.140	8,530	0.110	1.880	7,670
0.50	253.0	0.100	0.070	0.125	5	2.340	10,000	0.115	2.030	9,000
0.60	304.0	0.120	0.080	0.135	5	2.590	11,350	0.120	2.240	9,950
0.70	355.0	0.120	0.080	0.140	5	2.760	13,720	0.125	2.380	11,050
0.75	380.0	0.120	0.080	0.140	5	2.840	13,800	0.130	2.450	11,630
0.80	405.0	0.120	0.080	0.145	5	2.920	15,500	0.130	2.515	12,150

Maximum working pressure—2,500 volts a.c. Y-circuit grounded neutral										
AWG					5 min.					
8	8.4	0.100	0.070	0.075	10	0.750	1,130			
6	13.3	0.100	0.070	0.080	10	0.840	1,440			
4	21.2	0.100	0.070	0.080	10	0.950	1,920			
2	33.6	0.100	0.070	0.085	10	1.095	2,320			
1	42.4	0.100	0.070	0.090	10	1.190	2,720	0.085	1.080	2,090
1/0	53.5	0.100	0.070	0.090	10	1.290	3,110	0.085	1.155	2,430
2/0	67.4	0.100	0.070	0.095	10	1.400	3,730	0.090	1.255	3,310
3/0	85.0	0.100	0.070	0.100	10	1.525	4,290	0.095	1.355	3,610
4/0	107.0	0.100	0.070	0.105	10	1.665	5,330	0.095	1.460	4,540
Circular inch										
0.25	127.0	0.120	0.085	0.110	10	1.835	6,000	0.100	1.625	5,560
0.30	152.0	0.120	0.085	0.115	10	1.980	6,740	0.105	1.735	5,830
0.35	177.0	0.120	0.085	0.120	10	2.090	7,920	0.110	1.835	7,160
0.40	203.0	0.120	0.085	0.125	10	2.210	8,730	0.115	1.950	7,880
0.50	253.0	0.120	0.085	0.130	10	2.410	10,150	0.115	2,095	9,110
0.60	304.0	0.130	0.095	0.135	10	2.630	11,700	0.125	2.290	10,360
0.70	355.0	0.130	0.095	0.140	10	2.800	13,720	0.125	2.420	11,550
0.75	380.0	0.130	0.095	0.145	10	2.865	14,240	0.130	2.500	12,070
0.80	405.0	0.130	0.095	0.150	10	2.995	15,010	0.130	2.565	12,650
Maximum working pressure—5,000 volts a.c. Y-circuit grounded neutral										
AWG					5 min.					
8	8.4	0.160	0.120	0.080	17	0.935	1,380			
6	13.3	0.160	0.120	0.085	17	1.025	1,680			
4	21.2	0.160	0.120	0.090	17	1.145	2,280			
2	33.6	0.160	0.120	0.090	17	1.280	2,770			
1	42.4	0.160	0.120	0.095	17	1.380	3,110	0.090	1.280	2,480
1/0	53.5	0.160	0.120	0.100	17	1.480	3,490	0.095	1.370	2,810
2/0	67.4	0.160	0.120	0.100	17	1.585	3,960	0.095	1.460	3,540
3/0	85.0	0.160	0.120	0.105	17	1.710	4,720	0.100	1.560	4,040
4/0	107.0	0.160	0.120	0.110	17	1.850	5,620	0.105	1.675	4,830
Circular inch										
0.25	127.0	0.160	0.120	0.115	17	1.965	6,220	0.105	1.765	5,780
0.30	152.0	0.160	0.120	0.120	17	2.120	7,450	0.110	1.875	6,540
0.35	177.0	0.160	0.120	0.120	17	2.220	8,160	0.115	1.970	7,400
0.40	203.0	0.160	0.120	0.125	17	2.330	8,930	0.115	2.080	8,080
0.50	253.0	0.160	0.120	0.130	17	2.530	10,400	0.120	2.240	9,360
0.60	304.0	0.160	0.120	0.140	17	2.740	12,000	0.125	2.390	10,600
0.70	355.0	0.160	0.120	0.145	17	2.900	14,030	0.130	2.530	11,860
0.75	380.0	0.160	0.120	0.145	17	2.980	14,680	0.135	2.600	12,510
0.80	405.0	0.160	0.120	0.150	17	3.070	15,440	0.135	2.680	12,980

IMPREGNATED PAPER-INSULATED, LEAD-SHEATHED CABLES—GENERAL DATA.—(*Continued*)

Size conduit		Cylindrical conductors						Semi-sector conductors		
		Thickness in inches								
		Insulation								
AWG	Sq. mm.	Between conductors	Between conductors and lead	Lead	*Kv. test, 15 min.	Maximum diameter over lead in inches	Approximate net weight in pounds per 1,000 ft.	Thickness lead in inches	Maximum diameter over lead in inches	Approximate net weight in pounds per 1,000 ft.
Maximum working pressure—7,500 volts a.c. Y-circuit grounded neutral										
AWG					15 min.					
6	13.3	0.200	0.150	0.090	24.5	1.150	2,400			
4	21.2	0.200	0.150	0.090	24.5	1.250	2,770			
2	33.6	0.200	0.150	0.095	24.5	1.400	3,280			
1	42.4	0.200	0.150	0.100	24.5	1.500	3,630	0.095	1.385	3,290
1/0	53.5	0.200	0.150	0.100	24.5	1.590	4,040	0.100	1.500	3,650
2/0	67.4	0.200	0.150	0.105	24.5	1.705	4,920	0.100	1.590	4,090
3/0	85.0	0.200	0.150	0.110	24.5	1.830	5,520	0.105	1.690	4,610
4/0	107.0	0.200	0.150	0.115	24.5	1.970	6,240	0.110	1.810	5,660
Circular inch										
0.25	127.0	0.200	0.150	0.120	24.5	2.090	7,320	0.110	1.900	6,230
0.30	152.0	0.200	0.150	0.125	24.5	2.240	8,180	0.115	2.010	7,010
0.35	177.0	0.200	0.150	0.125	24.5	2.330	8,490	0.120	2.110	7,620
0.40	203.0	0.200	0.150	0.135	24.5	2.560	9,300	0.120	2.215	8,320
0.50	253.0	0.200	0.150	0.135	24.5	2.650	11,090	0.125	2.370	9,840
0.60	304.0	0.200	0.150	0.140	24.5	2.840	13,200	0.130	2.515	11,130
0.70	355.0	0.200	0.150	0.150	24.5	3.050	14,700	0.135	2.660	12,380
0.75	380.0	0.200	0.150	0.150	24.5	3.080	15,400	0.135	2.720	13,040
Maximum working pressure—12,500 volts a.c. Y-circuit grounded neutral										
AWG					15 min					
2	33.6	0.290	0.220	0.105	39.5	1.675	4,020			
1	42.4	0.290	0.220	0.110	39.5	1.775	4,400	0.105	1.710	3,780
1/0	53.5	0.290	0.220	0.110	39.5	1.865	4,840	0.105	1.785	5,260
2/0	67.4	0.290	0.220	0.115	39.5	1.980	5,350	0.110	1.885	5,000
3/0	85.0	0.290	0.220	0.120	39.5	2.105	6,950	0.115	1.990	5,550
4/0	107.0	0.290	0.220	0.125	39.5	2.245	7,210	0.115	2.095	6,220

Circular inch										
0.25	127.0	0.290	0.220	0.125	39.5	2.350	7,870	0.120	2.195	6,800
0.30	152.0	0.290	0.220	0.130	39.5	2.500	8,690	0.125	2.305	7,590
0.35	177.0	0.290	0.220	0.135	39.5	2.610	9,400	0.125	2.400	8,220
0.40	203.0	0.290	0.220	0.140	39.5	2.720	10,100	0.130	2.510	8,930
0.50	253.0	0.290	0.220	0.145	39.5	2.925	12,200	0.135	2.660	10,440
0.60	304.0	0.290	0.220	0.150	39.5	3.110	13,600	0.140	2.810	11,750
Maximum working pressure—15,000 volts a.c. Y-circuit grounded neutral										
AWG					15 min.					
2	33.6	0.330	0.250	0.110	47	1.795	4,230			
1	42.4	0.330	0.250	0.110	47	1.850	4,690	0.110	1.840	4,670
1/0	53.5	0.330	0.250	0.115	47	1.985	5,040	0.110	1.915	5,070
2/0	67.4	0.330	0.250	0.120	47	2.100	6,040	0.115	2.020	5,560
3/0	85.0	0.330	0.250	0.120	47	2.220	6,670	0.120	2.115	6,130
4/0	107.0	0.330	0.250	0.125	47	2.360	7,610	0.120	2.220	6,810
Circular inch										
0.25	127.0	0.330	0.250	0.130	47	2.440	8,110	0.125	2.325	7,390
0.30	152.0	0.330	0.250	0.135	47	2.620	8,960	0.130	2.430	8,200
0.35	177.0	0.330	0.250	0.140	47	2.740	9,550	0.130	2.530	8,860
0.40	203.0	0.330	0.250	0.145	47	2.840	10,370	0.135	2.640	9,570
0.50	253.0	0.330	0.250	0.150	47	3.050	12,770	0.140	2.790	10,880
0.60	304.0	0.330	0.250	0.155	47	3.240	14,000			
Maximum working pressure—20,000 volts a.c. Y-circuit grounded neutral										
AWG					15 min.					
1	42.4	0.420	0.315	0.120	62	2.150	6,180	0.120	2.130	5,640
1/0	53.5	0.420	0.315	0.125	62	2.300	6,430	0.120	2.215	6,000
2/0	67.4	0.420	0.315	0.125	62	2.340	7,280	0.125	2.305	6,670
3/0	85.0	0.420	0.315	0.130	62	2.460	7,900	0.125	2.440	7,300
4/0	107.0	0.420	0.315	0.135	62	2.605	8,730	0.130	2.515	7,990
Circular inch										
0.25	127.0	0.420	0.315	0.140	62	2.715	10,040	0.135	2.620	8,610
0.30	152.0	0.420	0.315	0.145	62	2.860	10,970	0.135	2.720	9,300
0.35	177.0	0.420	0.315	0.145	62	2.960	12,360	0.140	2.820	10,100
0.40	203.0	0.420	0.315	0.150	62	3.070	13,700	0.145	2.935	10,750
0.50	253.0	0.420	0.315	0.155	62	3.310	15,200	0.150	3.090	12,830

IMPREGNATED PAPER-INSULATED, LEAD-SHEATHED CABLES—GENERAL DATA.—(*Continued*)

Size conduit		Cylindrical conductors						Semi-sector conductors		
AWG	Sq. mm.	Thickness in inches			*Kv. test, 15 min.	Maximum diameter over lead in inches	Approximate net weight in pounds per 1,000 ft.	Thickness lead in inches	Maximum diameter over lead in inches	Approximate net weight in pounds per 1,000 ft.
		Insulation								
		Between conductors	Between conductors and lead	Lead						
Maximum working pressure—25,000 volts a.c. Y-circuit grounded neutral										
AWG					15 min.					
1	42.4	0.520	0.390	0.130	77	2.445	6,910	0.130	2.450	6,010
1/0	53.5	0.520	0.390	0.135	77	2.550	7,660	0.130	2.530	6,610
2/0	67.4	0.520	0.390	0.135	77	2.650	7,990	9.135	2.610	6,920
3/0	85.0	0.520	0.390	0.140	77	2.680	9,360	0.135	2.720	8,010
4/0	107.0	0.520	0.390	0.145	77	2.920	10,210	0.140	2.830	8,560
Circular inch										
0.25	127.0	0.520	0.390	0.145	77	3.000	11,460	0.145	2.940	9,200
0.30	152.0	0.520	0.390	0.150	77	3.170	13,370	0.150	3.040	10,300
0.35	177.0	0.520	0.390	0.155	77	3.255	14,200	0.150	3.140	11,500
0.40	203.0	0.520	0.390	0.155	77	3.380	15,300	0.155	3.260	12,400
0.50	253.0	0.520	0.390	0.155	77	3.550	17,400	0.155	3.400	14,600

* Testing circuit three-phase *Y*-connected grounded neutral.

CABLE CALCULATIONS

The purpose of this chapter is to condense as far as possible a recent article[1] on the usual calculations in connection with the transmission of power by underground cable. This abstract will give a list of symbols to be used in all the formulas, a group of formulas dealing with the ordinary cable constants such as resistance, capacity, inductance, dielectric loss, etc., and another group of formulas dealing with the calculation of current-carrying capacity as limited by temperature rise. The tables and figures will also be given. It is the intention that any calculation can be obtained from the formula given, in terms of the symbols which are defined, and in terms of the usual constants for the electrical materials which are given partly in the figures and partly under the list of symbols. In addition, a few comments will be added where it seems necessary to make the formulas clear.

List of Symbols

The following is a list of symbols used, together with numerical values of some of the constants:

A = size of conductor in circular mils.
Cos ϕ = power factor of the insulation at a given temperature and frequency (see Formula 3).
D = outside diameter of the lead sheath in inches.
D_1 = inside diameter of the lead sheath in inches.
d = conductor diameter in inches.
E = working pressure between conductors in kilovolts.
e = working pressure to neutral in kilovolts.
f = frequency.
G_n = geometric factor.
H = heating constant of duct in thermal ohms per foot.
I = current per conductor in amperes.
I_s = induced sheath current in amperes.
k = specific inductive capacity or permitivity of the insulation (about 3.3 for impregnated paper, 5 for varnished cloth, and 6 for rubber, the last two varying through a wide range).
L = self-inductance of conductor in henries per 1,000 ft. of conductor.
M = mutual inductance of conductor and sheath of a single-conductor cable in henries per 1,000 ft. of conductor.
N = number of similar cables in a duct bank.
n = number of conductors in a cable.
R = conductor resistance in ohms per 1,000 ft.

[1] Simons, "Calculation of the Electrical Problems of Transmission by Underground Cables," *Elec. J.*, p. 366, 1925.

R_o = added effective conductor resistance in a single-conductor cable, due to induced sheath currents, in ohms per 1,000 ft.
R_{ac}/R_{dc} = ratio of alternating- to direct-current resistance (skin effect).
R_s = resistance of lead sheath in ohms per 1,000 ft.
R_t = resistance of conductor at T° centigrade.
R_{th} = thermal resistance to I^2R loss between conductors and base in thermal ohms per foot.
R_{th}' = thermal resistance to dielectric loss between conductors and base in thermal ohms per foot.
r_{th} = thermal resistance between the conductors and the sheath of a three-conductor type-*H* cable.
r = radius of a conductor in inches.
r_o = inner radius of a tubular conductor in inches.
r_1 = radius of inner conductor of a concentric cable in inches.
r_2 = inner radius of the outer conductor of a concentric cable in inches.
r_3 = outer radius of the outer conductor of a concentric cable in inches.
r_4 = inner radius of the lead sheath in inches.
r_5 = outer radius of the lead sheath in inches.
ρ_4 = thermal resistivity of insulation in watt-centimeter units (850 for paper or V. C., 650 for rubber).
ρ_o = resistivity of copper in microhms per centimeter cube.
ρ_1 = electrical resistivity of the insulation in megohm-centimeter units.
ρ' = thermal resistivity of the earth in watt-centimeter units, which may vary widely, but 150 is an average value.
S = distance between centers of conductors in inches.
t = belt insulation thickness in inches.
T = conductor insulation thickness in inches, or temperature in degree centigrade.
T_o = allowable temperature of insulation in degrees centigrade.
T_G = base temperature of the earth in degrees centigrade (about 20°).
V_s = voltage induced along sheath of single-conductor cables in volts to neutral per 1,000 ft.
W = I^2R loss in watts per foot of cable.
W_{DL} = dielectric loss in watts per foot of cable.
X_L = $2\pi fL$.
X_M = $2\pi fM$.

Cable Constants

Most of the following formulas are self-explanatory. It will be noted that formulas 14 to 19 inclusive require a knowledge of the geometric factor, and they will, of course, be different, depending upon whether the cable is connected in the usual three-phase way, or three conductors against the sheath, or two conductors against the third conductor and the sheath, etc. The

geometric factor should be obtained from Formula 1, which gives two of the geometric factors for a three-conductor cable and one for other numbers of conductors. If any connection other than that given in the figure is to be used, the relationship between the various geometric factors is explained in the group of formulas given in (20).

$$D_1 = d + 2T \text{ for one-conductor cables} \tag{1}$$

$$D_1 = 2(d + 2T) + 2t \text{ for two-conductor cables (round duplex)} \tag{2}$$

$$D_1 = \left(1 + \frac{2}{\sqrt{3}}\right)(d + 2T) + 2t \text{ for three-conductor cables} \tag{3}$$

$$D_1 = (1 + \sqrt{2})(d + 2T) + 2t \text{ for four-conductor cables} \tag{4}$$

$$R_T = \frac{234 + T}{259} \times R_{25} \tag{5}$$

$$L = \left(0.1404 \log_{10} \frac{S}{r} + 0.01525\right) + 10^{-3} \text{ henries to neutral per 1,000 ft.} \tag{6}$$

For single-conductor cables with induced sheath currents flowing.

$$\text{Resistance} = R + R_o = R + \frac{X_M{}^2 R_s}{X_M{}^2 + R_s{}^2} \text{ ohms per 1,000 ft.} \tag{7}$$

$$\text{Inductance} = L - \frac{X_M{}^2 M}{X_M{}^2 + R_s{}^2} \text{ ohms to neutral per 1,000 ft.} \tag{8}$$

$$V_s = IX_M \text{ volts to neutral per 1,000 ft.} \tag{9}$$

$$I_s = \frac{IX_M}{\sqrt{X_M{}^2 + R_s{}^2}} \text{ amperes} \tag{10}$$

$$R_s = \frac{1503\ \rho_s}{r_5{}^2 - r_4{}^2} = 10^{-6} \text{ ohms per 1,000 ft.} \tag{11}$$

$$M = 0.1404 \log_{10} \frac{2S}{r_5 + r_4} \times 10^{-3} \text{ henries to neutral per 1,000 ft.} \tag{12}$$

$$L = \left[0.1404 \log_{10} \frac{S}{r} + \frac{0.1404 r_o{}^4}{(r^2 - r_o{}^2)^2} \times \log_{10} \frac{r}{r_o} + 0.01525 \frac{(r^2 - 3r_o{}^2)}{(r^2 - r_o{}^2)}\right] \times 10^{-3} \text{ henries to neutral per 1,000 ft.}$$

For tubular conductors. (13)

$$\text{Capacity, } C = \frac{0.0169nk}{G} \text{ microfarads per 1,000 ft.} \tag{14}$$

$$\text{Thermal resistance, } R_{th} = \frac{0.00522\rho G_1}{n} \text{ thermal ohms per foot} \tag{15}$$

$$\text{Insulation resistance, } R = \frac{0.989\rho_1 G \times 10^{-6}}{n} \text{ megohms per mile.} \tag{16}$$

$$\text{Charging current, } I = \frac{0.106Efnk}{G} \text{ milliamperes per 1,000 ft.} \tag{17}$$

$$\text{Three-phase dielectric loss, } W_{DL} = \frac{0.000106e^2fn^2k \cos\phi}{G_2} \text{ watts per foot of cable} \tag{18}$$

$$\text{Leakage } g = \frac{0.106fkn \cos\phi}{G_2} \times 10^{-6} \text{ mhos per 1,000 ft. to neutral} \tag{19}$$

G_1 = geometric factor, A, B, and C *vs.* sheath, from Formula 1.
G_2 = geometric factor, three-phase operation, from Formula 1.
G_3 = geometric factor, A *vs.* B (C and sheath floating or connected to midpoint of transformer) $= 2G_2$.
G_4 = geometric factor, A *vs.* B and $C = 1.5\,G_2$.
G_5 = geometric factor, A *vs.* sheath (B and C insulated)
$$= \frac{3G_1 + 2G_2}{3}.$$
G_6 = geometric factor, A *vs.* B and sheath (C insulated)
$$= \frac{G_2(6G_1 + G_2)}{3G_1 + 2G_2} \tag{20}$$
G_7 = geometric factor, A *vs.* B, C and sheath $= \dfrac{9G_1G_2}{6G_1 + G_2}$
G_8 = geometric factor, A and B *vs.* sheath (C insulated)
$$= \frac{6G_1 + G_2}{6}$$
G_9 = geometric factor, A and B *vs.* C. and sheath
$$= \frac{4.5G_1G_2}{3G_1 + 2G_2}.$$
Where A, B, and C represent the three conductors.

Current-carrying Capacity

To calculate the permissible current-carrying capacity of a cable of given makeup, knowing the size of conductor and the number of similar cables in a duct bank, use the fundamental formula (21). All the quantities in the formula are known except T_o which is given in (22), and R_{th}, given in (23), making it possible directly to calculate the permissible current. If it is desired to find the size of cable which will carry a given current, it is necessary to assume the size and then apply (21) until a size is found which will carry the required current.

If the problem involves the use of single-conductor cables in which induced sheath currents are allowed to flow, R_{th} should be found by (24) instead of (23). If with three-conductor or single-conductor cables, it is desired to include the dielectric loss, the more complete formula (26) should be used, which includes the effect of copper, sheath, and dielectric losses and skin effect. In this formula R'_{th}, the thermal resistance to dielectric loss, should be found by (23) for multi-conductor cable and by (25) for single-conductor cable. R_{th} in the denominator is the thermal resistance to copper and sheath losses, and (23) should be used also for multi-conductor cable and (24) for single-conductor.

If the duct line contains different types of cable, *i.e.*, for different voltages or with different sizes of conductor, etc., the above

will be very approximate only, and the original article should be consulted.

To calculate the carrying capacity of three-conductor type-*H* cables, for the first term of R_{th} in (23), substitute r_{th} from (27)

$$I = 0.281\sqrt{\frac{A(T_0 - T_G)}{nR_{th}}} \tag{21}$$

$$\left.\begin{aligned} T_0 &= 85 - E \quad \text{for paper insulation} \\ T_0 &= 75 - E \quad \text{for varnished-cambric insulation} \\ T_0 &= 60 - E/4 \ \text{for rubber insulation} \end{aligned}\right\} \tag{22}$$

$$R_{th} = \frac{4.44G_1}{n} + \frac{4.93}{D} + N \tag{23}$$

$$R_{th} = 4.44G + \frac{R + R_0}{R}\left(\frac{4.93}{D} + N\right) \text{ thermal ohms per foot} \tag{24}$$

$$R'_{th} = 2.22G + \frac{4.93}{D} + N \tag{25}$$

$$I = \frac{0.281}{\sqrt{R_{ac}/R_{dc}}}\sqrt{\frac{A(T_0 - T_G - W_D l\, R'_{th})}{nR_{th}}} \tag{26}$$

$$r_{th}{}^* = \frac{1}{0.67\sqrt{1/(r + T)G} \times \tan h\ [10.59\ \sqrt{r + T)/G}] + 0.28/G} \tag{27}$$

where $G = \log_e \dfrac{r + T}{r}$

*Simons, "Calculation of Carrying Capacity of Type-H Cable," *Elec. J.*, p. 59, 1926.

CHAPTER XIV

OPERATING THE UNDERGROUND SYSTEM

The cost of operating the underground system is low compared with the overhead system. It is just as necessary to make periodical inspections of the underground system, however, as it is to inspect the equipment in the power house or substation. In a dense underground section the inspection should be made at shorter intervals than in an outlying district where there are a small number of cables, but inspections should be frequent enough to discover small defects before they develop into serious burn-outs, gas explosions, etc. Some definite plan should be laid out to cover the whole system at least every 30 days and this inspection should cover definitely the items to be looked for. If an inspector goes out to make an inspection of an underground system without a catalogue of items to look for, he is liable to become mechanical and forget some important items. A record should be kept to show what has been found and a record of what has been done to remedy the trouble found. In every city there are gas mains, and leaks occur, and this gas goes through the earth to the conduit system and finds its way through joints of the ducts and into the manholes. The same is true of sewer gas. This is a very dangerous situation and should be taken care of at once. A cigarette may be cast on the manhole cover by a passer-by and cause an explosion. A safety lamp should be used to test for gas. Sewer gas usually comes from the drain in the manhole due to the sewer trap in the manhole being dry. Water should be put into the trap at once. When illuminating gas is present, the manholes should be aired to locate from which direction the gas is coming. This information should be given to the gas company as soon as possible so that the leak may be repaired without delay, and after repairs are made all manholes in the locality should be aired because the gas lying in the ducts and manholes is just as dangerous as that which comes from gas mains. Gas explosions are experienced more in winter than in summer. In the winter the earth is frozen on the surface and the gas flows

to conduits and manholes. The manhole covers in many cases are frozen down tightly so that there is no escape for the gas. Explosions of this sort have wrecked buildings, killed people, and caused fires in manholes resulting in a general shutdown of substations. This is a very important part of inspection and should be carefully observed. In some cities it has been found necessary to install vent pipes from manholes to curbing or to poles to prevent explosions.

Considerable heat is radiated from heavily loaded underground cables. This fills the duct and manholes with hot air. A vent pipe will carry off this heat to some extent but the cables are constantly moving in the duct due to expansion and contraction. This is found more pronounced in an Edison system or railway d.-c. system, due to the higher peak load. The movement of cables back and forth in the duct is liable to cause a chafing at the edge of the duct and if duct protectors are not under the cable a hole may be worn through the lead sheath. In time moisture will enter and cause a short-circuit on the cable. For this reason the inspector should report the absence of protectors under cables at duct entrances of manholes. Bonds should be inspected to see that they are intact and connected to the cables and to note whether or not there has been any undue heating. See if the hangers are in place and the cables resting thereon. Check the hangers for rusting; see if tags are on every cable in the manhole; check against the office record; inspect fireproofing. Many times when repairs have been made on cables the fireproofing has been removed in small sections and not replaced. Look for leaks, that is, insulating compound leaking from joints or cracks in the lead near the duct edge. Look for holes in the cable and joints. Many times a splice may blow open and then go back into service and be operating in this condition. Use a hand mirror to inspect the back of cables; inspect inside of junction boxes; see if the doors are fastened with rubber gasket and all bolts are present; inspect fuses and contacts; test fuses for contact; check all lug contacts on buses; also check feeders for overload. Where there are other electrical apparatus in manholes such as oil switches, transformers, etc., they should be inspected by a special inspector trained for this class of apparatus. The presence of mud and water in manholes should be reported. Running water in a manhole usually indicates a leak in the city water supply and should be reported to the proper persons so that repairs can be made.

This should be checked up after the report is made to see that repairs are completed. Water leaks may undermine the conduit and cause considerable trouble to the cables by the conduit settling and causing the cables to stretch until the lead breaks, then moisture enters the insulation and causes a burnout. In a case of this kind it is best to locate the place and excavate around the conduit to make repairs or relay the conduit. It should be the duty of everyone in the employ of the company to keep an eye open for excavations in a street where it is known that the company has conduit, to report it to the underground department so that investigations can be made to see that no damage has been done to the conduit. A great many contractors will excavate for buildings and undermine conduit without reporting the fact to the company, causing a great deal of damage and interrupting service. The inspector while making his rounds should bear it in mind to report excavations near or at conduits.

A written report should be made for each manhole inspected. The report should show good and bad conditions in the manhole, then a detailed report should be submitted for each manhole showing work to be done. This is given to a jointer or repair man to make such repairs as are necessary. He in turn reports what repairs were made, reporting the amount of labor and material used.

Terminal-pole Inspection.—All potheads outside and inside should be inspected. The disconnect outdoor type should be inspected by a cable jointer. Examine the porcelain for cracks and possible leaks in the castings. The disconnect should be pulled and the contacts cleaned and a little vaseline put on them. To insure easy disconnecting in an emergency all clamps, bolts, and supports for the cable and potheads should be inspected. The pipe on the pole should be inspected for rusting. The concrete around the pipes and pole should be inspected for cracks next to the pole. These cracks should be filled with pitch to prevent rotting of the pole.

Periodic insulation tests on all underground cables should be made. The insulation test will not always discover trouble, but it will show up moisture. The simple method to make an insulation test is with a megger. This will pick out bad spots in cable, splices, and potheads and will avoid serious trouble later. If a low reading is obtained, it should be checked up with a high-voltage test to break it down and locate the trouble. Hot spots

on low-voltage cables are often due to wet insulation. One case of this kind discovered before a breakdown in service occurs will pay for a great many days of testing.

Temperature readings should be made on conduits and manholes. The general opinion of operating engineers is that the cost of temperature surveys is justifiable. Hot spots have been discovered where they were suspected and more efficient loading of cables has been made possible. The most general practice seems to be to measure the temperature of the air in the manholes of conduit lines known to be heavily loaded or to measure the temperature of the air in a vacant duct a few feet in from the manholes in lines which are heavily loaded or where excessive temperatures are suspected due to adjacent steam lines or other similar causes. When abnormal temperatures are encountered, some power companies survey the entire line by measuring the temperature in a vacant duct at suitable intervals of 25 to 50 ft. The practices used for measuring manhole temperatures and duct temperatures adjacent to manholes vary considerably. Ordinary mercury-in-glass thermometers are used as well as maximum-indicating mercury-in-glass thermometers. Also, the ordinary pressure-type graphic instruments are employed. For measurements along the duct it is obvious that an electrical type of temperature-measuring device is most convenient, either a resistance-type detector with a whetstone-bridge type of instrument or a thermocouple-type detector with a potentiometer-type of instrument. The latter method is more generally employed.

CHAPTER XV

FAULT LOCATION

There are many methods used for trouble hunting in the underground system. If the method used gets results and trouble is located in a reasonable length of time, it should be satisfactory. There are three types of faults, grounded conductors, short-circuits and open circuits. While these three cover all faults encountered, faults may be found to include all three types. Grounded conductors are the most common type encountered and are caused by insulation breakdown between the conductor and lead sheath. It may be one or more conductors. Short-circuits are not so common as the grounded conductor, but in three-conductor cables this type of fault occurs and is usually the easiest to find providing it is a low-resistance short; that is two conductors are well connected together at the place of fault. A high-resistance fault is hard to locate. The open circuit is not common but often occurs in large cable splices. These are not so easy to find. There are three methods of locating faults: the cut-and-test method, inspection of manholes, and testing from a power-house substation or other point of advantage. If the cut-and-test method is used, the cable in trouble is divided in two parts and cut in the center of its total length. A test is made in both directions to discover in which direction the fault is. Then this length is divided in two parts and another cut is made, and again a test is made to discover the direction of fault. This is a very lengthy operation and a very expensive method of locating faults. The manhole-inspection method is sometimes used when all other methods fail. This method, however, consumes considerable time and requires a large number of men to cover a long underground line in several hours. The best method is the method of testing from a power house or substation. If possible, testing apparatus for every kind of fault should be provided. The apparatus, however, should be portable so that if it should become necessary to move it to a more advantageous point this can be done. When making tests for locating faults great care

should be taken to see that the cable is disconnected from the bus or lines. A clearance should be secured from the load despatcher and all switches should be tagged to hold for the person getting clearance. If the feeder goes to several points it should be cleared at each place and tagged to hold. When a fault is reported, the first thing to do after clearance is made is to analyze the fault, that is, test the cable to find out the number of conductors grounded in the case of a three-conductor cable, or if short-circuits, open, etc. This test can be made with a dry battery and telephone receiver, or with a test lamp or voltmeter using direct current. A megger is very useful for this purpose. It will give the insulation value of each conductor under test. After the cable is tested from one end, the other end of the cable should be grounded to test for open circuit. If one conductor is grounded, however, it is best to test from both ends. In many cases of fault a conductor may be grounded and open, or open and grounded from one end and test very high for insulation on the other end. There are many combinations of this kind, and great care should be taken in analyzing faulty cables. A little time spent this way in the beginning may save hours of lost time later.

It may be found that the ground or short-circuit is of a very high resistance and its location is very difficult. If this is the case apply high voltage to the conductor in question to carbonize the fault. This will make a better path to ground and enable the tester to get a definite location.

Carbonizing Faults.—In a great many cases of high-tension cable faults there is no metallic path between conductors or between conductor and sheath heavy paper or other insulation preventing the current bridging over the fault. In order to secure a closed circuit for testing and locating, a path must be made across the insulation. This is accomplished by the application of pressure high enough to start a flow of current across the gap and just enough current to carbonize the insulation without destroying the material by combustion.

The Lundin fault locator can be used for this purpose. It is a very compact and portable apparatus. It consists of an analyzer and interrupter together with various types of exploring coils. The analyzer is for the purpose of indicating the condition of the cable as to fault or leakage, reducing the resistance of a fault and carbonizing it; also to obtain some idea of the nature and probable location of the trouble.

The interrupter is used for the purpose of sending a signal out over the faulty cable. The exploring coils are used to pick up the signal given out by the interrupter.

The other necessary apparatus is an a.-c. supply of 110 volts or thereabouts of about 50-amp. current capacity; also, one or more standard lightning transformers sufficient to obtain a pressure, when properly connected, of at least 50 per cent of the working voltage of the circuit in trouble.

After a solid ground or short-circuit is secured the power bridge can be used in locating faults in power cables. The resistance of the cable being so low, avoidance of error due to contact and lead resistances must be carefully provided for. This bridge has been so designed and constructed that lead and contact resistances are practically eliminated, thus making possible accurate locations.

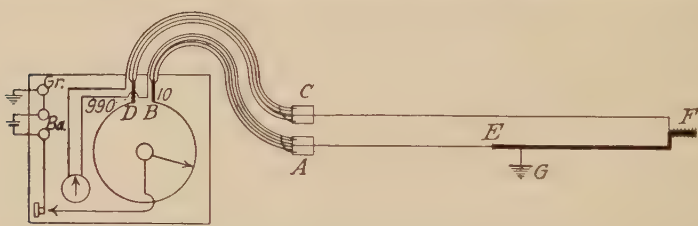


Fig. 214.—Diagram of connections used in connection with Leeds and Northrup Power Bridge.

The instrument operates on the slide-wire principle. A galvanometer is provided as are also the necessary leads for connecting to the cable under test. Locations are made by the Murray loop method.

The bridge is provided with two flexible leads about 7 ft. in length. Each lead is composed of two No. 4 braided and stranded copper cables in parallel. At the ends of the leads there are heavy contact blocks for clamping on to the ends of the cable to be measured. These clamps are so designed that they may be fastened either directly to the cable under test or to a switch or to busbars upon which the cables may terminate. Figure 214 shows diagrammatically the connections used in this instrument. One good wire is necessary to use this method and this wire must not only be clear of grounds and short-circuits but must be continuous. *C* is the good wire and *A* is the faulty wire. *C* and *A* are connected together by a jumper at the far end. This jumper should be wire as large as the wire in the cable and connection

should be made by clamping. The galvanometer is connected across C and A and the slide wire or resistance is connected to leads. The clamps must be so fastened at A and C that the contact resistances will be very small. This contact resistance will figure as an error in the measurement. If, for instance, the contact resistance were equal to 0.001 ohm, and the wire were of such a size that 0.001 ohm were equal to the resistance of 20 ft. of the cable, there would be an error of 20 ft. in the location of the fault. For this reason, all contact resistance throughout the loop from A to C must be negligibly small.

The fault is located by the usual Murray formula. If, for instance, the galvanometer shows no deflection when the contact is at 300 on the scale, it would indicate that the fault is at a distance from A equal to $\frac{300}{1,000}$ of the total length of the loops from A to C.

The Woodpecker Telefault.—This instrument can be used for locating low-resistance faults. The exploring coil is applied to the faulty cable, and, if the fault is not passed, the sound of the instrument in operation will be distinctly heard in the receiver.

The Organ Grinder.—In this method a small amount of direct current is impressed upon a faulty cable and for easy detection, interrupted at a low frequency (1 cycle in 2 sec.) at which the capacity effect of the cable is negligible. The apparatus for detecting the signal current consists of small portable generators whose field is excited by the signal current. The field is a split ring which can be passed around the cable. The armature is rotated by means of a small crank operated by hand and is connected to a millivoltmeter. When cranking the generator, the observer makes adjustments to neutralize all foreign currents and then notes the periodic swing of the millivoltmeter needle, on both sides of zero. When the fault has been passed, the regularity of the swing of the needle will not be evident. It is claimed that signal currents of considerably less than 1 amp. can be readily detected. This means that not a very large voltage is required to send a small direct current along a faulty conductor to the point of fault, the resistance of which may be relatively high.

Locating Faults on Street-lighting Circuits.—Routine tests should be made for grounds. The fault can be isolated by testing between lamps where series lighting is used. A cut-out placed at

the base of the lamp posts will enable the circuit to be opened half-way and tested, then half-way on the remainder until it is run down to one section. Then if there is a solid ground, the bridge method can be employed for locating the fault by using a good rubber-covered wire for the good wire. If a high-resistance ground is developed, then the Lundin fault locater is used, burning a path to the ground. Then the bridge or an interrupter with an exploring coil can be used with good results. Vacuum tubes connected in the exploring-coil circuit to amplify weak signal currents are being used. In some cases signals are found to be weak due to high-resistance faults and amplifiers are used to good advantage. Exploring coils can be conveniently carried on the side of an automobile and if provided with amplifiers will detect signals from cables below the street or from wires overhead. Similar applications of amplifiers serve to great advantage for locating faults in submarine cables of ordinary depth.

CHAPTER XVI

DUCT SPLICING OF CABLES FOR REINSTALLATION [1]

"Duct splice" is the term applied to the type of splice that has been developed for lead-covered cables in which the diameter of the completed splice is not appreciably greater than the diameter of the original cable and which, therefore, permits the pulling of both the cable and the splice into the duct. It is usually impossible to make assignments for the installation of stock cable without causing considerable loss from cutting off the excess length. The duct splicing together of two or more short or odd-length sections eliminates this waste by adapting the available pieces of cable to the required specific conduit lengths.

FIG. 215.—General view of salvage room equipment is available for ten setups high voltage test cage is shown in rear. Each man is a specialist; the one nearest the camera is lead burning the sleeve, the second man is soldering outer strands of 2,500,000 C.M. S. C. cable and the third is insulating 11,000 volt cable duct splice.

[1] By C. H. SHAW, The New York Edison Co.

When 13,200- and 11,000-volt, 3 × 350,000-cir. mil cable is converted into scrap, there is a loss of about $1.30 a foot, this being the difference between the value of good cable and the recovery of copper and lead. The loss in junking cables of smaller capacity and of lower voltage types is somewhat less, but the percentage loss in these smaller sizes may be larger because the amount of labor and factory costs involved in their manufacture forms a larger percentage of the total cost in the smaller cables than in the larger ones, and particularly those of large current-carrying capac-

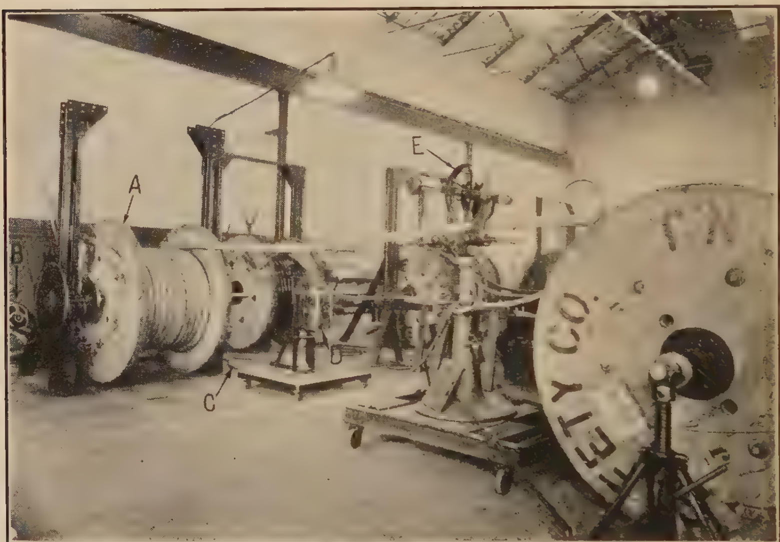


Fig. 216.—Arrangement of equipment for inspecting and measuring cable reel on left (A) is turned by chain driven gear motor speed being controlled through flexible cable, (C) from controller, (D) which is mounted on a movable truck. Operator stands with hand on controller as cable is being reeled. Measurements made by standard equipment. (E) mounted on truck.

ity. There is a loss of $1.10 a foot on 300-volt, 2 × 1,000,000-cir. mil concentric cable in which there is a larger amount of copper than in the high-voltage cable and a slightly lower value in the manufacturing process. If it costs $60 to make a 11,000-volt, 3 × 350,000-cir. mil cable duct-splice, it is seen that when two 25-ft. pieces are converted into usable cable, the saving is 2 × 25 × $1.30 = $65, and that it is, therefore, economical to duct-splice any section over 25 ft. in length.

The following table indicates the minimum lengths that it has been found economical to resplice into long sections by means of

duct splices for several types and sizes of cables that are used in underground distribution and transmission systems. The figures have been arrived at by balancing the cost per foot of the salvage and duct-splicing process against the loss that otherwise would be incurred if the cable were converted into scrap.

MINIMUM LENGTHS OF CABLE TO DUCT SPLICE

Conductors		Operating voltage	Type of cable	Insulation	Minimum length
Number	Size				
3	350,000 cir. mil	11,000	Triplex	Paper	25 ft.
2	1,250,000 cir. mil	300	Concentric	Paper	25 ft.
2	1,000,000 cir. mil	300	Concentric	Paper	25 ft.
1	2,500,000 cir. mil	300	Single conductivity	Paper	20 ft.
1	500,000 cir. mil	300	Single conductivity	Paper	20 ft.
1	350,000 cir. mil	300	Single conductivity	Paper	20 ft.

The work of reconditioning the cables includes not only the duct splicing itself, but a careful inch-by-inch examination and repair of the lead sheath as it is passed in front of two experienced inspectors, the removal of all portions of the cable that may appear to have been damaged during installation or withdrawal of the cable, particularly near the former duct-edge bends, a careful remeasuring of the cable to check up on the length of the section when it is returned to stock, and for the more important cables—an electrical test that is equal to the standard factory test.

The general precedure for making duct splices has been carefully standardized during the past 10 years. Details of the splice, however, have been improved from time to time and adjustments made for changes in cable size and insulation thickness, as the development in the art of cable manufacture has produced minor changes. These duct splices, of which thousands have been in service for several years, have been found by experience to be extremely reliable. The only burn-outs that have ever been recorded on this system as occurring in duct splices took place, in two instances, in the failure of rubber-insulated cable that was duct spliced during the war when no other cable for the particular installation was available. Duct splicing of rubber-insulated

cable for 6,600-volt service is a difficult problem and would not, ordinarily, be undertaken even with the present knowledge and experience in duct splicing. One instance may be cited where recently a cable failed in the duct which, upon removal, was found to contain three duct splices, but the failure had occurred

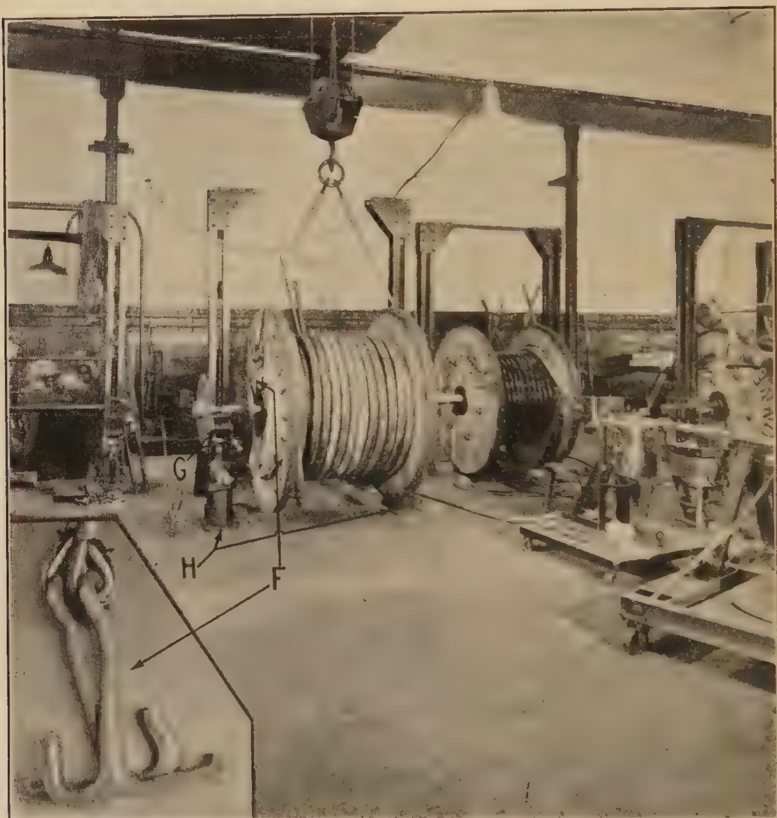


FIG. 217.—Handling reels. Five ton crane with sling and special design of lifting hooks (F) handles all cable and reels. Note that shaft has just been lifted off roller type cradle (G) Cradles may be lifted by hydraulic jacks (H) if desired. Drive chain is shown removed from large gear.

midway between two of these duct splices. The greatest reliance is placed upon this type of cable splice, and sections of cable that contain duct splices are used without any discrimination, being made up as part of feeders which, perhaps, may otherwise contain entirely new cable, without the slightest hesitancy or doubt as to their satisfactory operation.

The greatest progress that has been made recently in duct splicing has been in the development of equipment for carrying out the details of the splices, and in facilities for testing, rereeling, and handling the cable in the cable salvage shop. As the operations of this department have become more extensive, it has been found desirable to provide as many labor-saving devices as possible. During 1925 it was found that the work of reconditioning cable had increased by more than 20 per cent over that of 1924, while the total cost of the salvage operation, including all expenses, such as the loss in cable due to cutting off defective ends of cable, and the cost of material used for cable splicing, has been reduced more than 25 per cent as compared with the total cost of 1924. This improvement was the result of combining all of the operations of cable salvage in one building where the most up-to-date devices had been installed. An overhead electric crane eliminates the necessity of moving reels by hand by bringing them to, and taking them away from, the inspection platform, and improved facilities for setting up the reels, new devices for straightening the cable before rereeling, together with innumerable minor improvements, have contributed to this cost reduction. It is expected that developments now in process of completion will result in still further reductions in unit cost.

For smaller companies, where the process of salvage and reconditioning cannot be carried on continuously because of the relatively small amount of cable that calls for this treatment, the cost of reconditioning will be relatively high at first since the training of the men and the cost of apparatus will be a considerable item. As the system expands, however, as new loads call for the increase in the size of the conductors in the underground systems and therefore requires the removal of the earlier installation, it will be found that there will be a growing requirement for cable salvage and within a very few years practically all of the larger companies will find it desirable to develop a competent cable-salvage organization if they are not to destroy large amounts of good cable which cannot be utilized efficiently on account of its short length, except through duct splicing.

During the year 1925, the New York Edison Company removed more than 1,275,000 ft. of cable from its underground transmission system and d.-c. distribution system, all of which passed through the salvage shop to be converted either into reserve stock, neutral cable, or scrap. There are two reasons for this

very large turnover of cable. The rapid increase in load density in the Borough of Manhattan in the d.-c. district, calls, not only for the increase in the size of the conductors on the main distribution network, but also requires the placing in operation of from two to three new d.-c. substations each year. When a new substation begins to pick up its load, the underground feeder system is rearranged so that the supply of current in the new substation district shall come entirely from the new station. This releases the feeders of the older adjacent stations and permits of their removal as soon as the new station feeders have been completed. This item called for the withdrawal of more than 500,000 ft. of $2 \times 1{,}000{,}000$-cm. concentric cable.

During 1925 the New York Edison Company made 630 duct splices for its d.-c. feeder cables, over 150 duct splices for its 11,000- and 13,200-volt transmission cables, and several hundred duct-splices for the 350,000-cir. mil, s.-c., and 500,000-cir. mil, s.-c. main cable. The splicing of the 200,000-cir. mil, s.-c. cable does not require an insulated joint since all of the cable of this size that is withdrawn from the system is reinstalled as neutral conductor with two live conductors of the larger ratings, and the installation requirements for neutral cable are usually in excess of the total amount of 200,000-cir. mil cable withdrawn, there is no occasion for duct splicing this smaller size for use as an insulated conductor.

The process of making duct splices that is described below has been developed by the New York Edison Company over a considerable number of years and has now reached a point where it becomes a regular part of the work of the distribution department to salvage and recondition, on a routine basis, every piece of cable that is withdrawn from the underground conduits, except when some serious damage had been the cause for the removal, such as a burn-out, water entering the cable through some defect in the lead sheath, or when the cable is of the one or two older types which are no longer installed for high-voltage service because of insufficient copper cross-section.

Duct Splicing 11,000-volt Feeder Cable.—(Cable diameter, $2\frac{9}{16}$ in; splice diameter, $2\frac{15}{16}$ in.; increase, $\frac{3}{8}$ in.)

Figure 218 shows three successive steps in the manufacture of a duct splice before the application of the "belt" insulation and lead sleeve. The most important feature of this type of splice is the staggering of the conductor joints so as to minimize the enlarge-

ment of the finished splice cross-section. In the Fig. 218 group *A* shows the three conductors of each cable, those on the right having been cut off at the proper connection locations. This causes a net loss of 18 in. of cable for each joint. Group *B* shows the

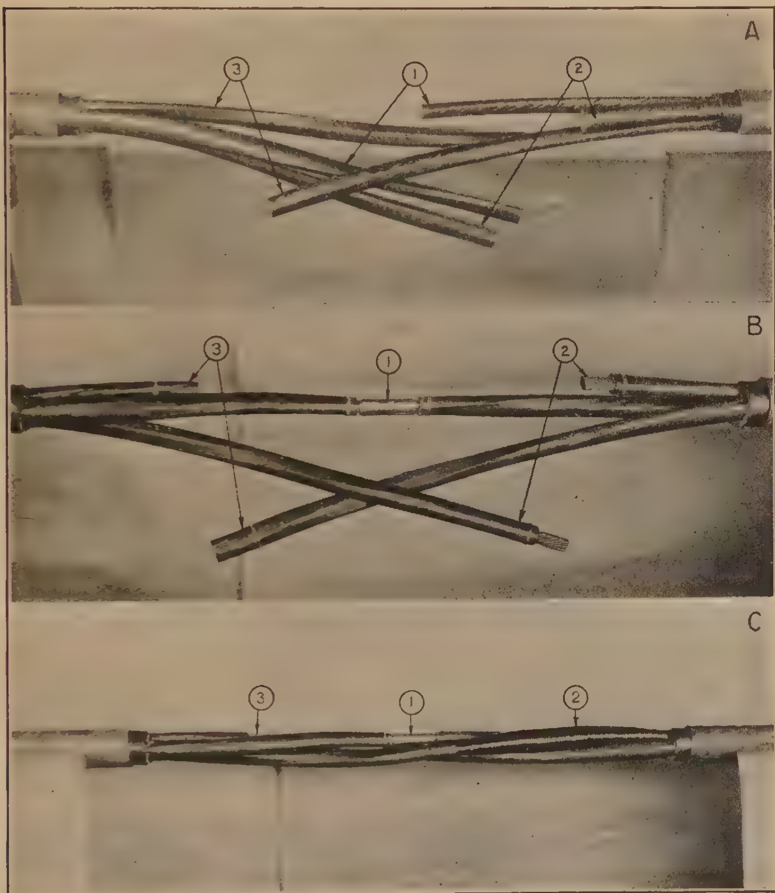


FIG. 218.—Three successive steps in making a duct splice before the application of the "belt" insulation and lead sleeve.

steps of tying the insulation before cutting back to receive the connectors (3), the paper cut back (2), and the connector in place (1). The ties are then removed, the paper penciled back ¾ in. from the end of the connector and this space filled with rove-filler ends so as to leave a flat, smooth surface for the insulation.

The insulation of each conductor splice consists of $\frac{9}{32}$ in. of black, varnished cambric tightly drawn, half-lap and treated with varnish for each layer as shown by (2) in group *C*. When each connector is insulated, rove filler is inserted lengthwise between the three conductors over which is applied a belt insulation of $\frac{5}{32}$ in. black varnished cambric. Outside of this belt there is added a belt of No. 40 B & S gage copper ribbon, 1 in. wide, half-lap, extending over the entire splice from lead to lead. This copper sheath is used principally to protect the insulation during the application of the lead sleeve but incidentally may have some value in distributing the electrical stresses.

The application of the lead sleeve is described below as the procedure is identical for all types of duct splices.

Duct Splicing 2 × 1,000,000-cir. Mil Concentric Cable.—(Cable diameter, $2\frac{1}{2}$ in.; splice diameter, $2\frac{3}{4}$ in.; increase, $\frac{1}{4}$ in.)

The most important feature of the concentric duct splice is the bringing together of the individual strands on the upper side of the splice so as to make the work accessible. In this cable there are three insulated pressure wires, which are treated throughout the process exactly like one of the conductor strands.

In Fig. 219 group *A* shows the outer conductor strands thrown back with the connector in place on the inner conductor. The next step is the application of the black varnished-cambric insulation $\frac{5}{32}$ in. thick. Then follows the connecting up of each of the outer strands to the corresponding strand on the other side. This is done by means of a smaller connector which is soldered exactly like the larger cables, each strand being held tightly in place by straps while the work progresses. Varnished cambric is added to the original paper between the inner and outer conductors in order to increase the diameter to allow for the thickness of the connectors in making up the outer strands. If the thickness of the inner insulation were not increased the outer strands would not lay smooth and tight.

After all strands have been connected as indicated in group *C* of Fig. 219 the outer belt of $\frac{5}{32}$-in., black varnished cambric is added which, in turn, is covered by a sheath of $\frac{1}{8}$-in. lead. The over-all length of this splice is 39 in.

Duct Splicing 2,500,000-cm. Single-conductor Cable.—(Cable diameter, $2\frac{7}{16}$ in.; splice diameter, $2\frac{15}{16}$ in.; increase $\frac{1}{2}$ in.)

This splice is relatively simple since strand connectors are not required but on account of the large amount of copper to be

handled two sets of group connectors are used. All of the inner strands are brought together under one connector, as shown in group *A* of Fig. 220 and the outer strands are grouped separately under another connector and are kept loose from the inner strands

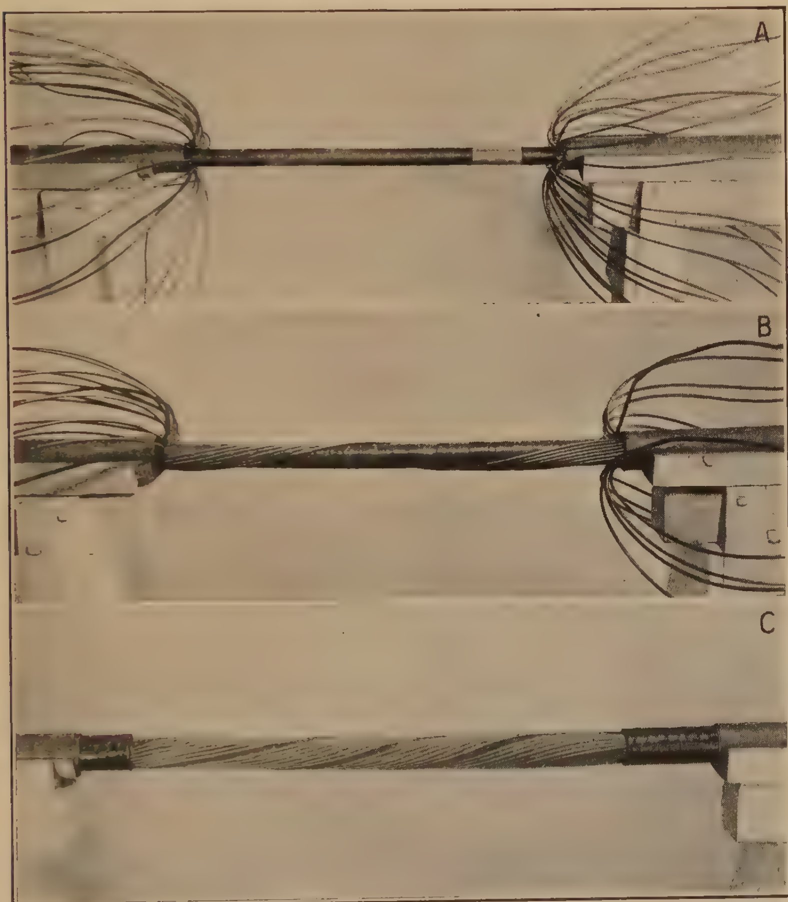


FIG. 219.—Outer connector strands thrown back, with connector in place on inner conductor.

by means of a long, thin sleeve shown in group *A*, so that as the cable is bent in handling there can be free movement between the outer strands and the inner core. If the solder from the outer connector were allowed to penetrate the inner strands it would stiffen the cable and might cause kinking later.

The pressure wires are treated as shown in group *C* and the black varnished-cambric insulation, 5/32 in. thick, is applied as shown in group *D*.

Attaching Lead Sleeve over Duct Splices.—Replacing the lead armor on a duct-spliced cable is one of the most important phases

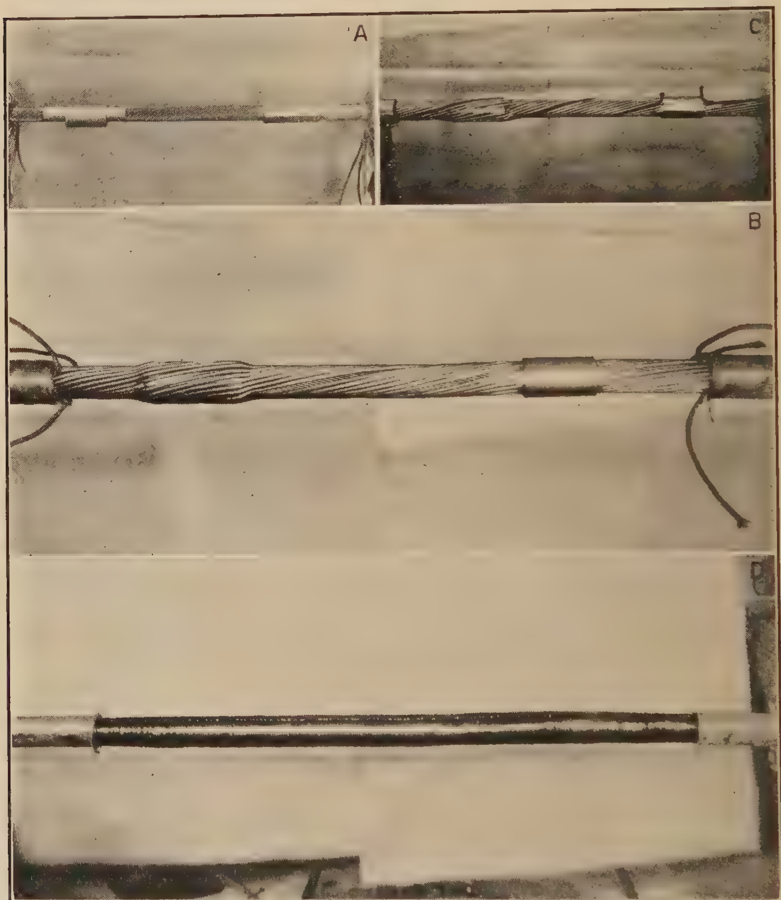


FIG. 220.—Outer strands are grouped separately under another connector.

of the work and is a process that requires a great deal of experiment and development before a satisfactory method was developed. The sleeve itself is a piece of lead tubing 1/8 in. thick and of such length and width when split open as to leave a butt joint lengthwise of the cable and an open gap of 3/8 in. at the ends,

as shown in *A*, *B*, and *C* of Fig. 221. The lead is firmly attached and formed to the insulated splice by means of band wires of soft iron that may be twisted up with pliers to give a tight fit. The sleeve is tooled carefully to the cable as the band wires are grad-

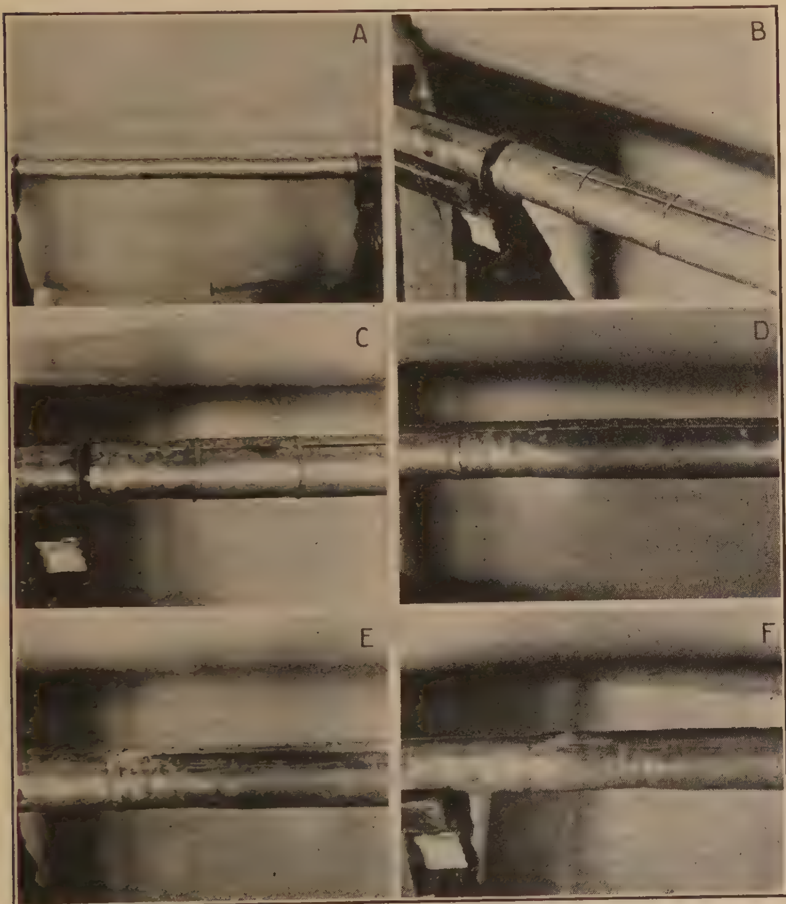


Fig. 221.—Attaching lead sleeve over duct splice.

ually drawn up, one at a time, leaving a narrow slot in the lead sleeve.

This slot is next "spot closed" by means of a lead burner's flame, using pure lead as the filler. After the slot is spot closed between all band wires, the bands are cut and removed, leaving the sheath as shown in group *D*. The lead burner then proceeds

to fill this slot with pure lead, giving two complete treatments, later scraping off all surplus lead. The ends of the original cable sheath are tooled down so as to lap over the new sleeve and a perfect lead wipe is completed with the lead burner's torch. No solder is used in any step of this work, as solder crystallizes if bent, while lead that has been "burned" properly has the same characteristics as pure lead. The lead strips that are used with the lead-burning process must be pure. Cable sheath will not do, as it contains impurities and must be scraped by hand just before using to insure the elimination of scale and oxidation. Closing the butt joints on the under side of the cable is accomplished by throwing the entire splice onto the other side of the make-up reel so that the under side of the cable is uppermost. Expert lead burners can complete the job from one position but there is always a danger that pinholes will remain.

INDEX